

JOURNAL OF THE
BOSTON SOCIETY
OF
CIVIL ENGINEERS



SEPTEMBER - 1932

VOLUME XIX

NUMBER 7

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Published Monthly, except July and August, by the Society
715 Tremont Temple, Boston, Massachusetts

Subscription Price, \$4.00 a Year (10 Copies)
50 Cents a Copy

Copyright, 1932, by the Boston Society of Civil Engineers.
Entered as second-class matter, January 15, 1914, at the Post Office
at Boston, Mass., under Act of August 24, 1912.

Acceptance for mailing at special rate of postage provided for in
Section 1103, Act of October 3, 1917, authorized on July 16, 1918.

*The Society is not responsible for any statement made or opinion
expressed in its publications.*

BOSTON
WRIGHT & POTTER PRINTING COMPANY
32 DERNE STREET

JOURNAL OF THE BOSTON SOCIETY OF CIVIL ENGINEERS

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FIFTEEN MILE FALLS LOWER DEVELOPMENT ON THE CONNECTICUT RIVER IN THE TOWNS OF MONROE, NEW HAMPSHIRE, AND BARNET, VERMONT

CLARENCE R. BLISS,* MEMBER

(Presented at the meeting of the Boston Society of Civil Engineers, May 20, 1931)

ANOTHER link in the chain of utilization of the Fifteen Mile Falls section of the Connecticut River has just been completed. In the broad field of adapting flowing water to the service of mankind, this chain seems to be a long one composed of diverse links. The first use of a river is usually for transport of the pioneer and of the raw products of forest and field. In this stage the quieter reaches are utilized for boat transportation with "carries" or "portages" around the swifter rapids. With increase of water-borne traffic these rapids and falls are frequently by-passed by canals and locks, or improved by other works, thus linking together the quiet reaches and extending the limits of uninterrupted boat travel. As civilization and settlement advance, the place of processing of raw products into more finished goods is carried nearer to their source. Manufacturing plants spring up where the swift waters provide adequate power, often supplementing or utilizing earlier transportation canals. Changing conditions, development of the art, improved equipment, and particularly the possibilities of economic transmission of power over long distances, frequently make attractive the redevelopment of these powers in greater magnitude and efficiency.

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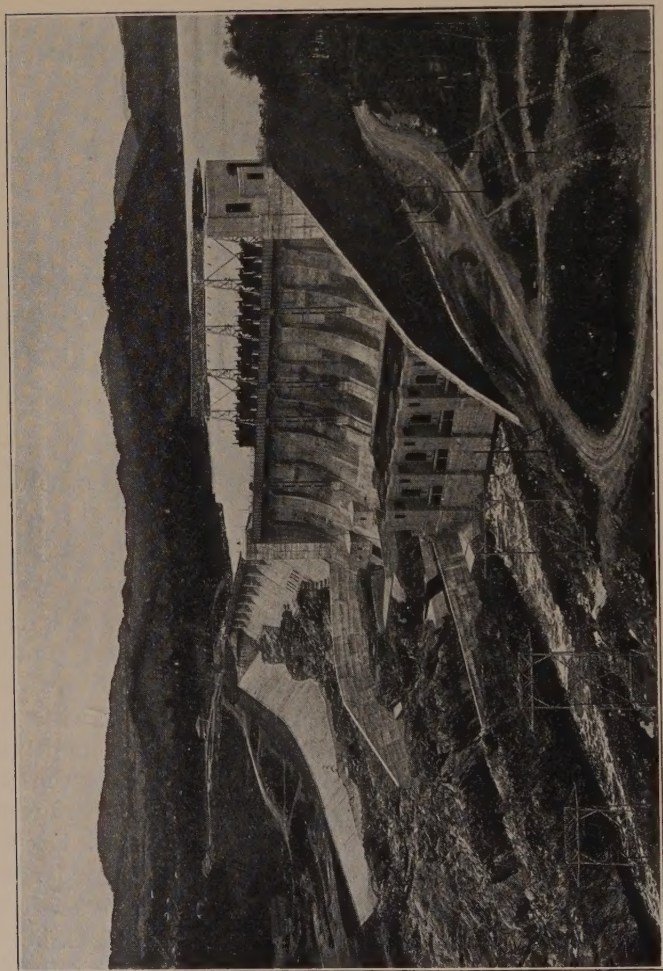


FIG. 1. — GENERAL VIEW OF COMPLETED PLANT

Following this it is not exceptional for these uses to be usurped by that highest use so far known in the service of mankind, the supply of potable water in large quantities for our rapidly growing cities; and as a result of further extension of urban populations there are cases where it has been necessary to abandon even this use and give up the site to recreation purposes.

Fifteen Mile Falls designates a reach of the upper Connecticut River of about that length extending from Gilman, Vermont, to within about a mile and a half of the mouth of the Passumpsic River. In this length, by a succession of rapids and swift water the river drops about 320 feet. Some seven miles below this swift water is a low natural falls known as McIndoes Falls. At this time it seems desirable to think of Fifteen Mile Falls and McIndoes as a unit. The river here forms the boundary between New Hampshire and Vermont. Littleton, New Hampshire, and St. Johnsbury, Vermont, are the largest near-by centers, and Monroe, New Hampshire, and Barnet, Vermont, are the townships in which the work to be described has been done, McIndoes being a village in Barnet. This stretch of river has been no stranger to the links of the chain of utilization just outlined, although, because of the location and the problems involved, it must be admitted that in many instances it proved impossible to complete the forging of the links.

In early days the river navigation, which developed from 1790 to 1830 or thereabouts, extended as far north as Wells River. Small boats were used from the head of the gorge above that place to extend this transportation to the foot of McIndoes Falls. It is said that DeWitt Clinton, builder of the Erie Canal, made a survey of the upper portion of the river in the interests of a canalization scheme, and in 1827 predicted that "these [Fifteen Mile] falls will undoubtedly be put to great use in the future," although he believed the rapids made impracticable the building of a canal. With the building of the railroads this river navigation died a natural death, and the only utilization of Fifteen Mile Falls proper of which we have record was for the transport of logs by driving. However, at McIndoes Falls a wing dam, extending to the middle of the river from the Vermont side, and a mill were in existence at the time the bridge was chartered, in 1803. In 1816 a charter was granted to extend the dam across the river, and mills were built on the New Hampshire side. In 1850 there was a sawmill, a gristmill and an oil mill on that side of the river. In later years the sawmill on the Vermont side had a capacity of 60,000 feet of lumber daily, with a planing mill and box factory in addition. In the season of 1892, 20,000,000 feet of lumber were cut out here, but about 1901 the big mill was closed

and in 1907 taken down. The gristmill on the New Hampshire side was abandoned shortly after, and in the great flood of 1927 the last remains of the dam were carried away.

During later years many studies were made for utilizing the potential power of Fifteen Mile Falls, but none were carried out, probably because of the cost and the lack of an attractive use or market for the power with the transmission facilities then available. It is interesting to note the evidently greater desirability of a site like McIndoes, with its low but concentrated falls and readily available pondage for the equipment

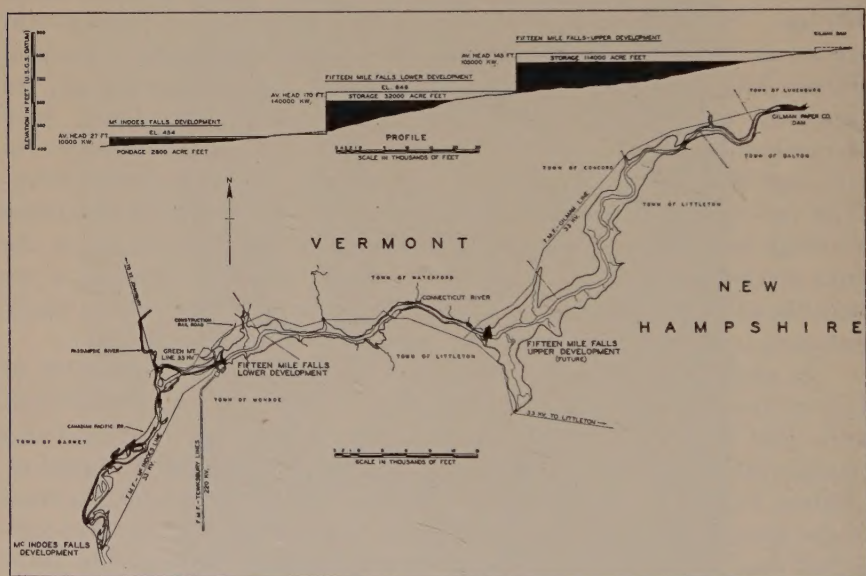


FIG. 2.—VICINITY OF FIFTEEN MILE FALLS. PLAN AND PROFILE

and needs of that day, as contrasted with the Fifteen Mile Falls, where the greater but more gradual fall requires larger structures to take advantage of it and provide the desired pondage. About four or five years ago the New England Power Association became interested in the possibilities of this portion of the river.

GENERAL SCHEME OF DEVELOPMENT

The Association's engineering studies showed it to be attractive to develop the Fifteen Mile Falls proper in two plants of relatively high capacity for low load factor use, the lower one at the very foot of

the Falls and the upper one about one mile downstream from the village of Waterford, Vermont, at the upper end of the lower pond. Such high capacity use would result at times in the discharge of water during relatively short periods of the day. A redevelopment of the low fall at McIndoes with a low capacity plant would permit taking advantage of the ample storage facilities of the flat intervening river in reducing these discharges to greater uniformity for economic use under this head. Therefore these three plants, of which two are now operating, may be considered as integral parts of one general development.

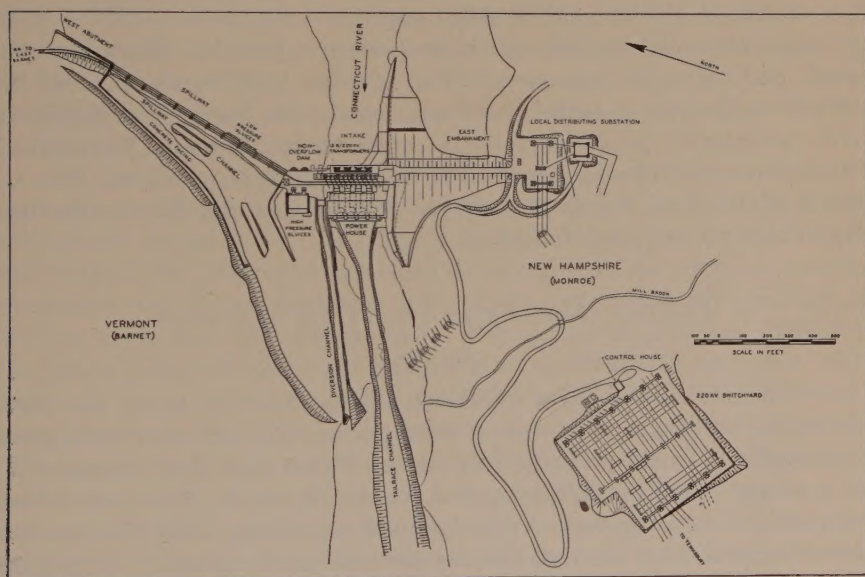


FIG. 3. — GENERAL LAYOUT

As planned, the upper plant would be designed for an average gross head of 145 feet, and a discharge of 11,000 c. f. s., with a nominal capacity of 105,000 kw. in four units. The design would permit of a drawdown of 40 feet, making available 114,000 acre feet of storage. The drainage area above this plant is 1,613 square miles, of which 83 square miles are controlled.

The lower plant has been constructed with an average gross head of 170 feet, a discharge of 11,000 c. f. s., and a nominal capacity of 140,000 kw. in four units. It is expected that after the construction of the upper plant this lower pond would not normally fluctuate more

than 5 feet to allow necessary operating flexibility. The design, however, has been based on an allowable drawdown of 40 feet, making 32,000 acre feet of storage available prior to the construction of the upper plant. The drainage area here is 1,650 square miles.

McIndoes has been constructed with an average gross head of 27 feet, a discharge of 5,000 c. f. s., and a nominal capacity of 10,000 kw. in four units. A drawdown of 6 feet is possible here, making 2,800 acre feet of pondage available.

The principal storages on the headwaters at present available benefiting these plants are the Connecticut Lakes, with about 88,000 acre feet of storage in First and Second Lake.

The electrical output of these present plants is distributed in small part to local customers. The greater part is transmitted at 220,000 volts from a switch yard adjacent to the Lower Development over two single circuit, three-phase transmission lines to Tewksbury, Massachusetts. Here connection is made to the transmission lines of the New England Power Association System and the Edison Electric Illuminating Company of Boston.

FIFTEEN MILE FALLS LOWER DEVELOPMENT

Geology

Available surveys and information regarding the lower site were extremely meagre, and it was at first planned to construct the Lower Development at the extreme foot of the Falls, with the structures all in a straight line extending square across the river. Moreover, there was little to be observed at the site itself, consisting as it did of a low New England river bank partly wooded and partly meadow, to suggest any more attractive layout. After surveys and geological investigations were extended, the presence of a ridge of trap rock and massive schist angling back upstream away from the river was noted on the Vermont river bank. With this to form the foundation or backbone of the spillway, the possibility of better ledge extending across the river made it desirable to move the plant some 200 feet upstream. The final design as carried out consists of an overflow spillway angling down to the river, founded on this trap ridge; an intake and power house across the river; and a rolled earth embankment supported by a high concrete retaining wall to tie into the earth river bank on the New Hampshire side.

In the investigation of the geology of the site the more usual methods of using core and well drills and test pits were supplemented by an

electrical sounding method. The application of the electrical method to the investigation of a dam site when properly subjected to the control of geologic theory proved a most successful means of supplying approximate geologic information quickly and indicating areas where more careful investigation by the other methods was necessary. It was used principally to obtain the depths to bed rock, and its indications were accurate to within about 10 per cent in the deeper cover.

The bed rock consists of trap and schist, the latter being in areas of massive schist, laminated schist and phyllite; or, in other words, varying from material practically as good as the trap to a soft, slaty rock with a highly developed cleavage. The shift upstream in location to take advantage of the trap resulted in founding the structures largely on the more desirable of the schists when trap was not available. These provided very good foundation material when excavated to depths beyond the effects of weathering.

On the New Hampshire bank there was a heavy blanket of glacial drift over the ledge rock. The ledge ran out almost horizontally under this glacial deposit after attaining a height of about ten or fifteen feet above the river. Our investigations indicated that the center of the old preglacial bed of the river was some 1,300 feet to the left, and about 40 feet lower than the present bed. The glacial overburden, about 150 feet deep, consisted largely of boulder clay, modified till, and clay, with two sand strata. Because of the depths to ledge it was decided to complete the tie to the New Hampshire bank with an earth embankment. The upper sand stratum extending to a depth of ten or fifteen feet below the proposed pond surface only imposed a slight deepening of the cut-off trench under the low end of the embankment. Geological investigations and percolation tests showed that the lower sand stratum, averaging about 10 feet thick and some 80 feet below pond surface, would not be troublesome. A layer of coarser gravel and sand some four or five feet thick in places immediately above the bed rock was believed to consist of discontinuous lenses as it pinched out in places, and since similar deposits have been proved to be discontinuous. This view was evidently correct, as very little seepage has been detected from this layer.

Access

Active work on the Lower Development started August 20, 1928, with the construction of a three-mile railroad connection from the Canadian Pacific Railroad at Inwood, Vermont, to the site, and extending up the river to the quarry and sand pit. This is typical side hill

location which entailed some 75,000 cubic yards of mixed excavation, and a 140-foot single span girder bridge at the Passumpsic River crossing. This bridge, of nearly a record span for its type, carries a single-track standard gauge railroad on an eighteen degree curve, necessitating extra spacing of the girders. It was completed, ready for traffic, eighty-nine days after design was begun.

In order to get an early start on the work at the dam it was necessary to truck considerable material and equipment to the site until the railroad could be completed. The existing road was entirely inadequate for this service, and almost continuous improvement and maintenance were necessary during this trucking period to make it adequate in width and metal for the traffic.



FIG. 4. — BY-PASS CHANNEL DURING HIGH WATER

Handling Water

The scheme adopted for unwatering the site was to divert the water by a channel through the ledge on the Vermont bank. Simultaneously with the excavation of this channel the lower stages of the retaining wall were constructed behind a coffer parallel to the New Hampshire shore. With the channel completed and the wall carried to sufficient height, coffer were constructed across the river above and below the site. These served to turn the water through the channel and permitted unwatering the area between them by pumping. Smaller

coffers were necessary to allow the unwatering of the entrance and exit of the diversion channel.

The long swift reaches of the Fifteen Mile Falls prevented the formation of an ice cover and allowed the water to become supercooled in its passage. The flat reaches of the river below the Falls provided an excellent collecting pan for the frazil ice resulting from this cooling. The work on the diversion channel was prosecuted through the winter, during which time the frazil in collecting clogged all the channels and piled up to a considerable height at the site, extending back upstream for some distance at times. The ice was nearly even with the tops of the coffer for long periods, and on several occasions threatened to overtop them. To alleviate the condition, considerable quantities of thermit, calcium carbide and calcium chloride were used, under the direction of Dr. H. T. Barnes of McGill University, in attempts to open up channels through the ice. Since the periods of greater ice formation and remedial work were usually followed shortly by warmer weather, it is impossible to state quantitatively just how successful these efforts were, but it seemed quite evident to observers that they were successful in facilitating the passage of the frazil and improving conditions at the job.

Diversion Channel

The diversion channel for passing the river flow by the site was some 1,400 feet long with a bottom width of 25 feet, and entailed 63,000 cubic yards of excavation, largely ledge. To control the flow through the channel and provide a base of operations for the final closure of the dam, the upstream portion of the non-overflow structure crossing the upstream end of the channel was constructed before the water was diverted. Two openings, 23½ feet wide and 29 feet high, were left for the passage of the river flows. These openings were separated by a 10-foot pier and liberally provided with stop log grooves, drains and concrete placing chutes to facilitate the final closure. A 9 by 10 foot sluice controlled by a Broome gate was also provided to by-pass the water around the closure section during the actual closure procedure. This Broome gate is now retained as an emergency bulkhead for both the low and high pressure sluices. The diversion was designed to pass 23,000 c. f. s. at all times, and the work within the main coffer was so scheduled as to be perfectly safe from damage in case of overtopping from higher flows during the flood season.

Spillway

The spillway located on the Vermont bank of the river is 850 feet long and from 20 to 80 feet high. A bridge over the crest has eleven spans 77 feet 9 inches long, and its 5-foot piers reduce the net length to 800 feet. The crest is at elevation 640 and 642, and is designed to pass 120,000 c. f. s. It contains six 7 by 9 foot sliding sluice gates at elevation 600, with a free discharge capacity of 20,000 c. f. s. These are

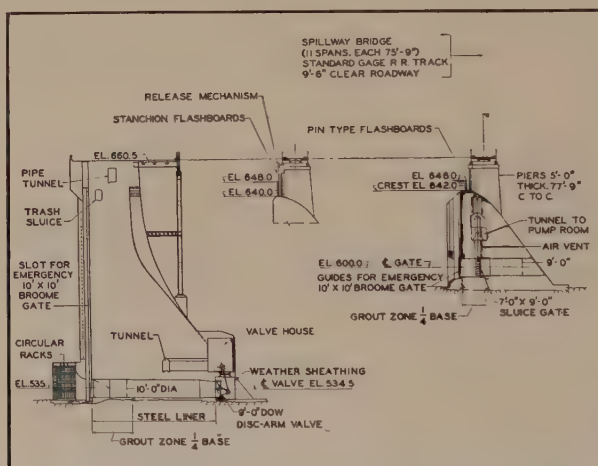


FIG. 5.—SPILLWAY AND NON-OVERFLOW SECTION

fluid operated with the pressure cylinders located in a longitudinal tunnel in the spillway, access to which may be had from the power house. Pressure for these cylinders is supplied by two 3,600 r. p. m. motor-driven centrifugal pumps, each of 150 gallons per minute capacity at 300 pounds pressure, to provide ample margin of safety in operation. As a measure of this margin 85 pounds pressure is the maximum that has been required to date. This capacity will permit of 4 feet of gate travel per minute on a single gate with one pump. An open sump tank of 750 gallons capacity is provided in the system. Inasmuch as freezing temperatures are not expected in the tunnel, water is used at present as the operating fluid with the addition of about 15 pounds of bichromate of potassium to 1,000 gallons of water. Experiment leads us to believe this will prevent rusting of the metal parts with the river water

used, and we expect we may be able to reduce this proportion somewhat in the future.

Flashboards are provided on the crest supported by pins or stanchions, and are designed for heights of 6 and 8 feet, depending on their location on the crest. The spillway, as in the case of all water bulkheading structures, was designed to be safe against sliding and overturning with water at elevation 654.5, and uplift on the base varying from two-thirds head at the heel to zero at the toe.



FIG. 6. — SPILLWAY DURING CONSTRUCTION

Flood Capacity — Flashboards

The four bays of elevation 642 crest provide a net total of 290 feet of pin type flashboards, and the seven bays at elevation 640, 510 feet of stanchion flashboards. The embankments and bulkheads have been built to an elevation which will permit discharge of 120,000 c. f. s. with 8 feet of free board. The six low pressure sluices will pass 20,000 c. f. s., and the generating units themselves better than 10,000 c. f. s. As contrasted with this 150,000 c. f. s. total flood capacity without including effect of pondage, the maximum flood of which we have record in this vicinity was about 50,000 c. f. s. The flows recorded at Orford from 1900 to 1921 when proportioned to the drainage areas do not exceed the combined capacities of the sluice gates and wheels, indicating that at no time in that period would it have been necessary to remove flashboards. As a matter of fact, the peak flows at Waterford bridge

during the two or three years that this gauge has been in existence have been higher than the indicated proportionate flows from the Orford or South Newbury records, so that it is probable that it actually would have been necessary to remove some flashboards occasionally during that period. Returning to the record figure of 50,000 c. f. s. above, were the flashboards all to be simultaneously released with water at their crest, we would have a discharge of 55,000 c. f. s. Were they to fail with 2 feet of water over the top in accordance with our usual design of pin flashboards, we would get something over 80,000 c. f. s. This indicates the necessity of having the greater part of the flashboards rigidly subject to manual control, so that we do not run the risk of increasing instead of reducing the flood peak. The pin type boards, supported on pipe pins, are our usual type, with two different pin spacings to assure that they all will not fail simultaneously. The stanchion flashboard equipment has been designed for three methods of operation:

1. Removal of single boards.
2. Release of all boards by lifting the needles with loss of boards, but recovery of the needles.
3. Emergency release at the top with loss of boards and needles.

Non-Overflow

A short section of non-overflow dam across the diversion channel forms the connection between the spillway and intake. It contains two steel-lined 10-foot diameter sluices controlled at the lower end by 9-foot motor-operated Dow disc-arm valves for free discharge under 115 foot-head. These were provided for by-passing water to plants below during the closure and filling period. They are still in operating condition, but are so retained simply in case of having to draw the pond below the sill of the penstock gates. These sluices are completely caged at the upper end by vertical trash racks composed of 4 by $\frac{3}{4}$ inch bars on 6-inch centers arranged in a semi-circle in plan.

Intake

The intake, of a buttressed design, provides for four 19-foot diameter penstocks tapering to 16 feet at the lower end. They are controlled at the upper end by Broome gates 19 feet wide by 29 feet 10½ inches high, arranged to traverse the entire length of the intake on 120-ton electric hoists, two gates being provided for the four openings. In addition, stop log grooves are provided to allow the release of the gates

for long-continued closures. The stop logs are steel beams with wood fillers, and were designed to be utilized temporarily in the final closure of the diversion channel. The sills of the gates are placed at elevation 560 to allow operation under a 40-foot drawdown. The intake openings are provided with racks for the full height, composed of round-edged flat bars $4\frac{1}{2}$ by three-eighths inch, spaced $2\frac{1}{8}$ inches in the clear, and are carried on steel supporting members. Racks and supports were designed for a 20-foot difference of head to allow for some clogging of the racks. A motor-operated traversing rack rake discharges trash into a sluice, which in turn discharges on to the spillway downstream from the flashboards. A 3 by 4 foot sluice gate is provided for scavenging the trash sluice at normal pond levels, and a pump will be installed for lower levels. Cooling water from the transformers on top of the intake is discharged into the gate slot behind the racks to alleviate ice troubles in freezing weather. The required air vent for the penstocks is provided in the concrete of the intake, and a 2 by 3 foot gate discharging into this serves as a penstock filler. The penstocks are located in the depressed filler spaces between the buttresses, and have concrete covers forming a continuous face on the downstream exposure of the buttresses. The covers serve to protect the penstocks from the weather and maintain a more equable temperature in case the penstocks are drained. The adoption of the buttressed design permitted a much better layout of the penstocks hydraulically by eliminating one angle and reducing the deflection of the other angle, as well as permitting the concreting program to continue much farther before being complicated by the penstock installation. The penstocks are on 45-foot centers with the buttresses 20 feet wide, giving 25 feet clear width for the penstocks. The penstocks are about 150 feet long, and weigh about 190 tons each. The design was based on an allowable tension on net section of 16,000 pounds per square inch; shear on rivets 12,000 pounds per square inch; and bearing on rivets 24,000 pounds per square inch. Maximum head for design is that due to a pressure rise above pond level varying from zero at the intake end to 25 feet of water at the outlet end. To the thicknesses thus determined one-eighth inch was added for corrosion, resulting in a total penstock thickness of nine-sixteenths inch at the upper end, and thirteen-sixteenths inch at the lower. All bursting pressures are designed to be taken in the plate. In addition, stiffener angles were provided for stiffening the pipe during erection, filling and emptying.

Transformer Service Building

For the purpose of servicing the transformers on the top of the intake a transformer service building is located at the east end of the intake. This is constructed of brick to match the exterior of the power house, and provides ample room for untanking and working on the transformers. A 90-ton hoist serves for dismantling and also for lowering freight down the 170-foot shaft to the power house floor.

Retaining Wall and Earth Embankment

The retaining wall and earth embankment are considered together because these two features are to a large extent interdependent upon each other. The retaining wall supports the embankment; the character and amount of the overturning forces acting on the wall are dependent upon the nature and condition of the fill. The retaining wall is of gravity section 170 feet high, extending 483 feet upstream and 410 feet downstream from the center of the dam. The embankment has a crest width of 25 feet at elevation 660.5, with slopes of 1 on 3 upstream, and 1 on $2\frac{1}{2}$ downstream for the upper 100 feet, changing to 1 on $3\frac{1}{2}$ and 1 on 3, respectively, below that. The intake joins the retaining wall at the center of the embankment, and thus is very effective in rendering its support at this point of maximum pressure. Boulder clay was available with which to construct the entire embankment, but to have used it to that extent would have resulted in a very slow draining fill as the pond is drawn, thus resulting in large pressures against the wall, and a greatly enlarged wall to withstand them. The embankment lying in the narrow "V" between the back of the wall and the excavated river bank provided a very narrow working space for the greater part of its height, and it proved unattractive to place it by the semi-hydraulic method which we have used frequently in the past. As a result of these conditions it was determined to construct the embankment by spreading and rolling, using boulder clay for the central portion between 1 on 1 slopes from the outer edges of the crest, and a much more pervious material for the remaining outer portions. This provides an impervious core for water tightness in the center of the dam, where its pressures could readily be transmitted to the end of the intake concrete. The faster draining qualities of the outer portion of the fill result in lower pressures on the wall supporting them, and allow a large saving in concrete over what would have been necessary to retain an all boulder clay embankment. Throughout the construction of the embankment

samples were taken from the embankment and borrow pits on the average of twice a week to be checked for permeability in the field laboratory. For this purpose the horizontal capillary permeameter was used in the field laboratory, and for comparative purposes tests were made from time to time with standard permeameters. The specifications covering the material used for embankment called for a co-efficient of permeability of not over 1.0×10^{-4} cm. per second for material for the

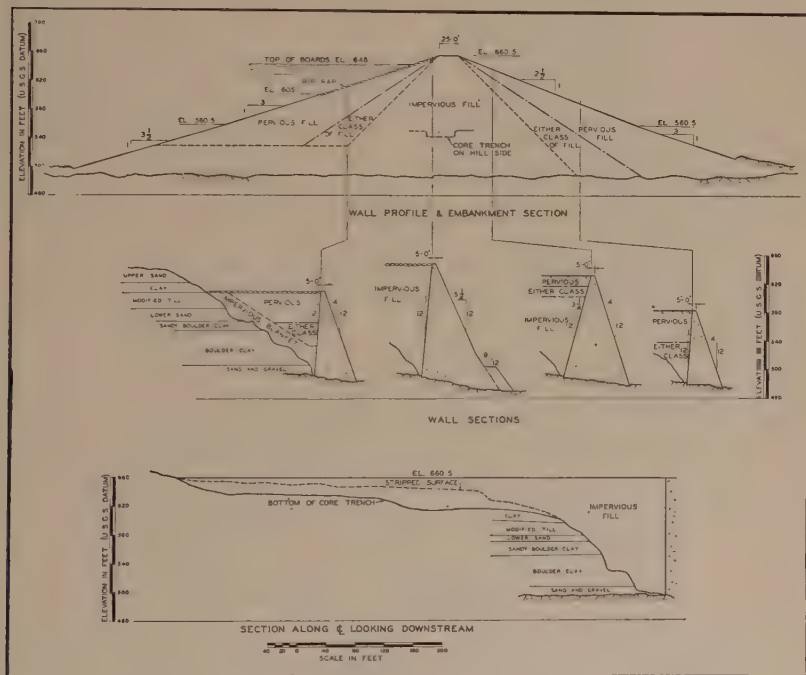


FIG. 7.—EAST EMBANKMENT AND RETAINING WALL

impervious core. Actually the material used was considerably tighter than this. The specifications for the pervious outer portions of the fill called for a co-efficient of not less than 20×10^{-4} cm., or a permeability of at least twenty times that of the material in the impervious core.

Power House and Hydraulic Equipment

The power house is of steel frame and brick construction, 236 by 99 feet on a concrete substructure. It is located immediately at the toe of the intake to minimize to the greatest degree possible the length

of the penstocks. To gain the 10-foot additional head resulting from the extremely long tailrace and provide the depth necessary for draft tubes, excavation had to be carried 35 feet below the original river bed, almost entirely in ledge rock. Turbines and generators are located in the generator room on the downstream side of the power house, with the switchboard, operating room and low tension switches in a gallery

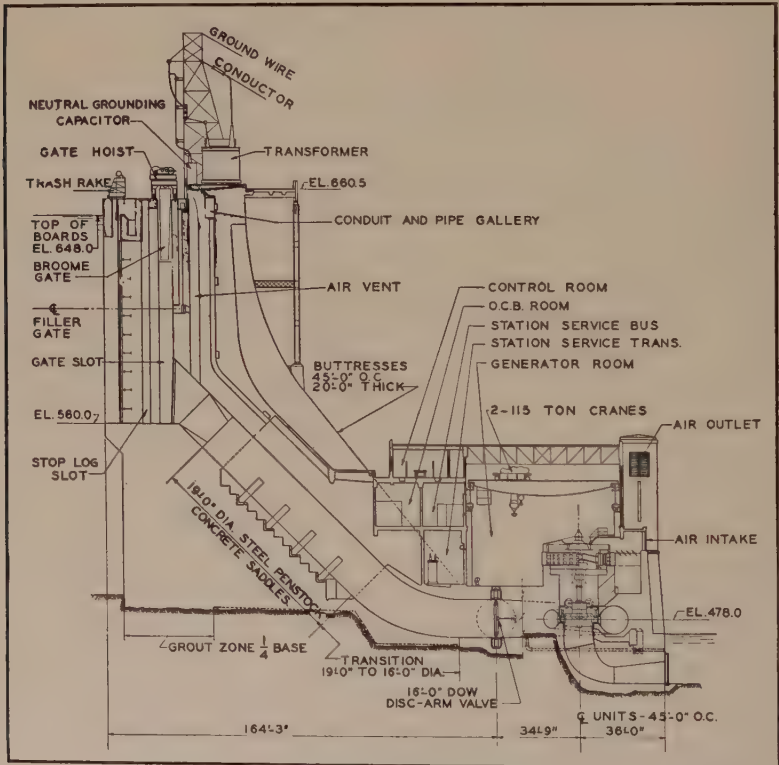


FIG. 8. — POWER HOUSE AND INTAKE. TYPICAL CROSS SECTION

upstream of the generating room. Access is had to the power house from the top of the intake through vertical shafts constructed in the junction of the intake and retaining wall. These shafts are provided with stairs and an elevator for passengers, and may be served by the crane of the transformer service building for freight and equipment. A light buff brick of varying shades was used for the exterior of the superstructure to harmonize with the surrounding masses of concrete.

The interior was lined with light buff brick of varying shades above a dado of darker brown salt-glazed brick in the finished portions of the building. Red quarry tile forms the floor surfacing in this same portion.

In the power house the penstocks are provided at the lower end with hydraulically operated 16-foot Dow disc-arm valves. Pressure is taken from a header connected by gate valves with all penstocks for normal operation, and two 3,600 r. p. m. motor-driven pumps can supply 150 gallons per minute each under 405-foot head for booster service. Pressure is also taken from a similar header which primarily supplies the transformer cooling water pumps, thereby providing a sort of water auxiliary station service bus. These Dow valves can be opened and closed from the generator floor, either by hand or by pilot motor control, and in an emergency can be closed from the switchboard with the pilot motor.

The turbines, four in number, are vertical, single runner wheels of S. Morgan Smith manufacture, direct connected to the generators. Turbines are rated at 54,000 horsepower each, and 3,050 c. f. s. under 170-foot net head at 138.5 r. p. m. They are set in plate steel spiral scroll cases connected by a short reducer section to the lower end of the Dow disc-arm valves of the penstock. Draft tubes are formed in the concrete of the substructure with draft tube liners of plate steel in the upper portion. The turbine steady bearing is of the oil-lubricated babbitted type with water cooling coils. A belt-driven pump (and a motor-driven pump with float control for emergency use) circulates this oil. The umbrella type of overhung generator has a Kingsbury thrust bearing below the rotor with the guide bearing combined on the thrust bearing collar, which is forged integral with the shaft. The guide bearing is also a bit unusual in that the shell is a series of shoes 9 inches high. These bearings are in a common oil pot with water circulation coils for cooling. Indicating thermometers with alarm attachment are embedded in each bearing.

The governor is the latest S. Morgan Smith development with 190,000-foot pounds capacity at 200 pounds pressure. Oil is used for the governor fluid in an open system, each unit being equipped with its own sump, pump and pressure tank grouped and connected in pairs, but the pairs are not interconnected. Pressure is supplied by 350 gallon per minute Quimby screw pumps, each being sufficient to supply the two governors in the group. Three complete strokes of the servo motor can be made with the tank fully charged at the start. The governor fly balls are motor-driven, taking current from the pilot exciter slip rings at 6.92 cycles. The speed indicator on the governor stand is actuated

by a magneto driven from the main turbine shaft through an endless spring belt.

The power house has been designed to take tail water to elevation 507, or some 35 feet above normal tail water, without flooding. This is 15 feet above the main generator floor. A very complete system of ventilation for cooling the generators and heating the power house has been installed. Outside air is drawn directly through louvres on the downstream face of the power house, and a duct system, into the top of the rotor. It is discharged through the sides of the stator to another duct, and thence to vertical stacks on the downstream side of the power house. These stacks are carried practically the full height of the power house,



FIG. 9. — DRAFT TUBE FORMS IN PLACE

thus obviating any chance of short-circuiting the air circulation, and also allowing the warm air to be discharged within the power house, and recirculated through the machines by adjusting the louvres and by-pass shutters provided for that purpose near the entrances and exits.

The generator room floor is served by two 115-ton traveling electric cranes, each with 15-ton auxiliaries. These cranes may be connected together by an equalizing bar to handle the rotor, which is the heaviest piece of equipment and weighs 230 tons without the shaft. Water for cooling the transformers at the top of the intake is supplied by two 3,600 r. p. m. motor-driven pumps of 350 gallons per minute capacity, each under 150-foot head.

Tailrace

The natural slope of the river continues at a considerably decreased rate for some 6,600 feet downstream to a point where a ledge and gravel bar forms a natural control beyond which the slope becomes very flat. Sub-surface exploration showed the excavation of a tailrace channel through this stretch to be possible, and studies indicated that by such excavation an additional head of 10 feet could be obtained at less than the average cost of the development for the resulting capacity.

A portion of this cut, about 1,400 feet in length, is wholly or partly in rock cut. This portion was enclosed by coffer dams, unwatered and

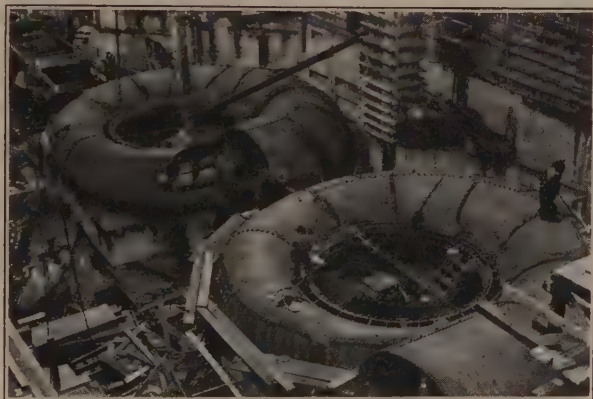


FIG. 10. — ERECTING TURBINE SCROLL CASES

excavated in the dry. The standard section in rock has a bottom width of 40 feet with side slopes of 2 on 1, and a maximum depth of about 35 feet. It is designed for a velocity of 7 feet per second at 10,000 c. f. s. discharge. A transition to the normal earth section is entirely made in the rock section.

The earth section has a bottom width of 110 feet, with side slopes of 1 and 2, and an average depth of 23 feet. It is designed for a velocity of 4 feet per second. This was excavated in the wet with a 355-ton drag line operating a 6-yard bucket on a 152-foot boom. The toe of the spoil bank was kept a minimum of 50 feet from the top of the cut to give a berm of that width at the former river bottom. At the lower end it proved possible in excavating to trim off some of the control lip

with a very moderate amount of excavation. The result of a conservative basis of computation for our planned, and the additional, excavation has been a lowering of 1 to 2 feet in the tailwater over our design.

Spillway Channel

The overburden above the ledge on the Vermont shore below the spillway was excavated to form a spillway channel to return the water to the river. Training channels were also excavated in the ledge itself.



FIG. 11. — POWER HOUSE INTERIOR DURING CONSTRUCTION

The shape of the channel and amount of excavation were determined by model experiments, as will be described later. At the upper end of the channel a slope wall of concrete serves to prevent erosion of the overlying earth. This wall is on a slope of 1 on $1\frac{1}{2}$, and is founded in the lower part on natural material, and in the upper portion on the fill of a supporting dyke of earth. The slab varies from 18 inches thick at the bottom to 12 inches at the top, and is supported at the bottom by a rugged toe block of concrete keyed into the ledge. It is divided into

sections by transverse ribs 2 feet wide by 2 feet 6 inches deep on 20-foot centers. The slab is reinforced for temperature stresses, with a center reinforcing system of 0.5 per cent of steel. A small parapet terminates and strengthens the slab at the top.

Electrical Layout and Equipment

The electrical layout is based on the unit system, each generator being connected directly to its own bank of transformers through a low tension oil circuit breaker without tying the units together until the high voltage bus is reached in the switch yard. The four vertical

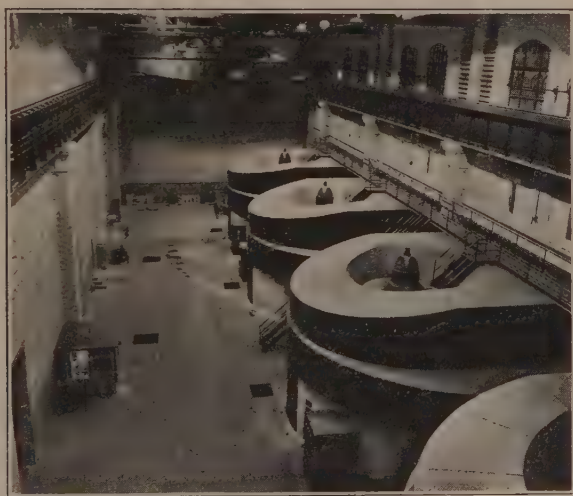


FIG. 12.— INTERIOR OF POWER HOUSE AFTER COMPLETION

generators are each rated at 39,000 kva., 90 per cent power factor, 13,800 volts, 60 cycles at 138.5 r. p. m. Each generator has its own direct-connected exciter and pilot exciter. The generator leads are taken directly through the low tension oil circuit breakers below the switchboard gallery, and through the concrete covers of the penstock trenches to the transformer banks on top of the intake. Each bank consists of three 13,000 kva., single phase, 13,800–230,000 volt transformers. The four high-tension circuits are then carried to the 220,000 volt switch yard, where they are combined into two circuits through gang-operated disconnects. The switch yard is arranged to further accom-

moderate two 220,000 volt circuits from the Upper Development, and one additional circuit to Tewksbury. A further 220,000 volt line is carried back to the local service yard at the end of the embankment. The local service transformer is rated at 12,500 kva., 3 phase, 230,000–66,000/33,000–2,300 volts. Distribution from this yard to customers in the locality and the tie to McIndoes is at present made at 33,000 volts, with provision for operation at 66,000 volts in the future. A 2,300 volt circuit is taken from this yard for local service to the operators' quarters, to the 220,000 volt yard, and for back-up to the power house station service.

All auxiliaries within the power house and on the dam, except the emergency exciter, are supplied with energy at 440 volts. A 500 kva., 3 phase, 13,800–460 volt station service transformer is connected to the terminals of each generator through disconnects, and through an oil circuit breaker and selector disconnects to a 440 volt station service double bus, at which all power feeds originate. In normal operation the bus is operated as a unit with one generator and transformer carrying all the load. The remaining transformers are kept connected to their respective units, but their 440 volt breakers would be open and are provided with an automatic switching scheme which will transfer the station service supply to the next available unit in case of the failure of the unit or transformer which happens to be supplying the load. At times when no generators are available for station service supply this service will be supplied from the local service transformer. Leads are brought back to the power house through cables from this transformer to a 2,300 volt indoor bus, which in turn is connected to the 440 volt bus through a 500 kva., 3-phase, 2,300–460 volt transformer. An emergency motor generator exciter is also fed from this 2,300 volt bus.

By-pass Closure

The by-pass channel through which the river had been diverted was closed as soon as it seemed that the spring run-off of 1930 was by. When the flow had dropped to a sufficiently low figure the two 23½ by 29 foot openings in the closure section were closed off by stop logs, and the flow diverted through the 9 by 10 foot sluice. Additional stop logs downstream from the area in which the initial closure was to be made permitted careful cleaning and placing of concrete in the dry in these chambers. With this block carried to sufficient height to divert ordinary flows through the high pressure sluices, the 9 by 10 foot sluice was closed and the sluiceway filled with concrete. These new pours of

concrete were then allowed to set for as long a time as possible to allow them to take nearly complete shrinkage. Following this the gap which was left in the non-overflow section above and downstream of the diversion closure was concreted as rapidly as possible, thus completing the closure to full height of the dam.

Models and Laboratory Investigations

In accordance with our usual and long-established practice we made liberal use of models and laboratory investigations in the layout

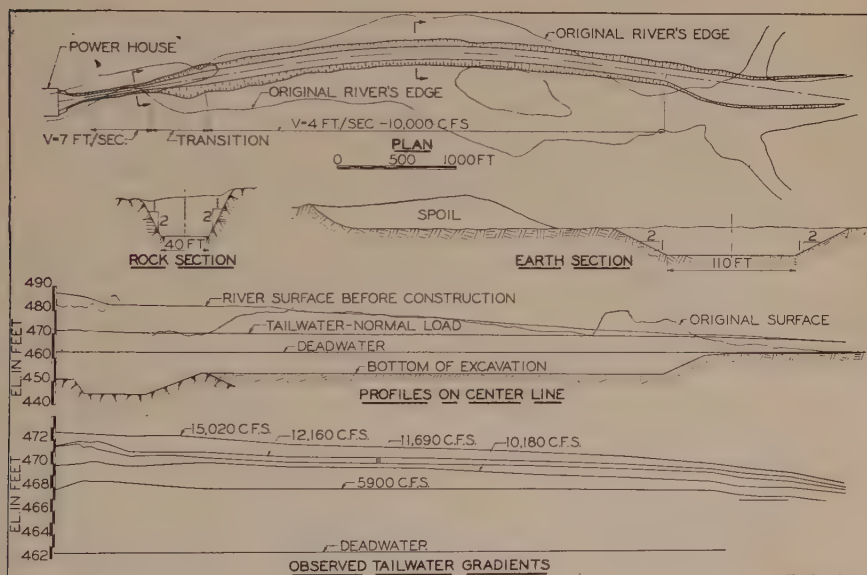


FIG. 13. — TAILRACE

and design of the entire development. These investigations were carried on principally in the laboratories of the wheel manufacturers, the hydraulic laboratory of the Worcester Polytechnic Institute, and at the Massachusetts Institute of Technology. The principal models which were constructed were as follows:

(a) A complete layout of the diversion channel and closure section, with which flow experiments were made to check our design computations.

(b) A general model of the spillway, intake, power house, spillway channel and river bed. This was used for visualizing the relation of the

structures with one another, and for determining the action of the spillway and sluices, the spillway channel alignment and excavation, and the effect on the river below. In determining the best layout of the spillway channel the model was made to scale with the underlying ledge rock in this area duplicated to scale in sawdust concrete and plaster of Paris, according to the best information obtainable. Sand was used to simulate the earth cover. Various layouts for stripping the earth cover, rock excavations and obstructions were then made in and on the model, and scaled flows were applied to it. The resulting flow and eroding characteristics of the discharge were observed and the best combination selected. The objective was to return the flood discharge to the river, for the most part in the rock cut portion of the tailrace, with the least probable erosion or deposition in undesired localities. Since it was impossible to duplicate all the small irregularities in the underlying ledge rock of the channel, it was felt that this determination could only be general in nature. After the closure was complete and water was available various sluice gates were opened to try the channel under action of the water. We were pleased to find that only a small amount of additional work was necessary to make conditions satisfactory.

(c) An architectural model which could be separated at several planes was made to assist the designers in visualizing the relations of the various parts of the intake and power house structure. No experiments were made on this model.

(d) The entire wheel equipment and the action of one part of the equipment on another were carefully studied by means of models. The wheel itself, of course, was developed very largely from models and the experiments on them. In addition, models were constructed and tested to determine the best size and shape of the draft tube and scroll case, the best angle for the speed ring vanes, and the effects of the disc-arm valves as an obstruction.

(e) A model was made of the intake, penstock and disc-arm valves, and experiments conducted upon it to determine the best shape for the intake and the best permissible curvature for the elbow.

(f) A model was made of the flashboard tripping device after we felt that we had a very satisfactory design for the details of this equipment. As a result of this model we were able to modify the tripping mechanism details with consequent benefits in cost, simplicity and reliability.

(g) In connection with the design of the high retaining wall we constructed the largest apparatus so far used in investigating earth

pressures, as well as apparatus for determining the co-efficient of friction of the fill material. Complete tests with this apparatus were carried out at Massachusetts Institute of Technology in collaboration with Dr. Charles Terzaghi, and it is expected that results of these experiments will be published. I might say in passing that among the more interesting indications of these experiments are the following:

1. With saturated materials the earth and water pressures combine, proper allowance having been made for reduction in unit weight of the earth under submergence.

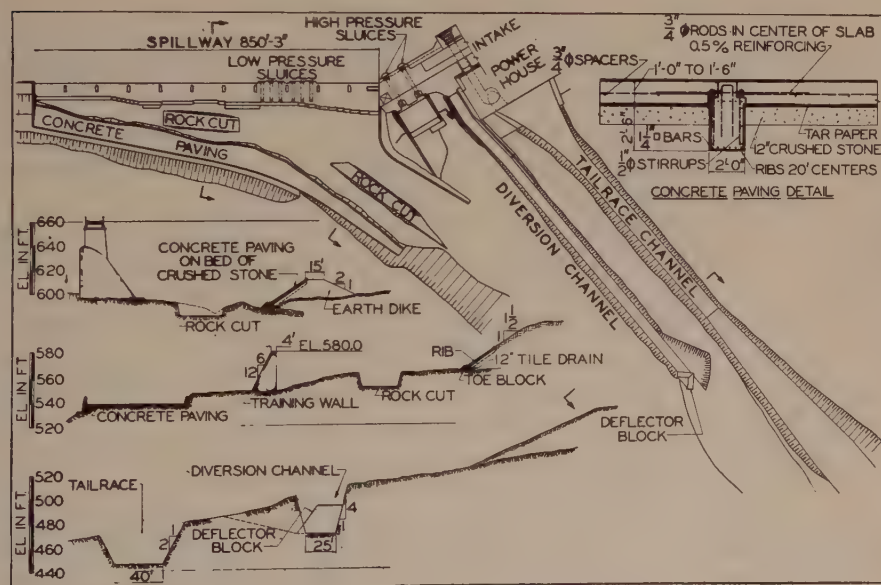


FIG. 14. — SPILLWAY CHANNEL AND EMBANKMENT PAVING

2. The co-efficient of internal friction is not affected by the condition of saturation.

3. The pressures exerted by the fill drop off rapidly as the wall yields slightly, so that a very slight yielding of the wall reduces the pressures to very reasonable amounts. The point of application of water pressure is at $\frac{1}{3}$ H, as is usual, but that of the earth pressure may go as high as 0.42 H in some cases.

4. Some unit weights of the materials used ran as high as 140 pounds per cubic foot.

Efficiency Tests

After the plant had been put into operation last fall the wheels were tested for power and efficiency by the Allen Salt Velocity method. The resulting efficiency of 93.8 per cent shown by this test is within 0.1 per cent of what we had predicted as a result of our tests on the models, and is 1.8 per cent better than the efficiency of 92 per cent guaranteed by the manufacturer. The power at maximum efficiency of 50,000 h. p. compares with 47,000 as predicted, and 45,000 as guaranteed.

Metering Equipment

To assist in best operation of the plant, and provide for records and tests of operation, a fairly complete equipment of water meters

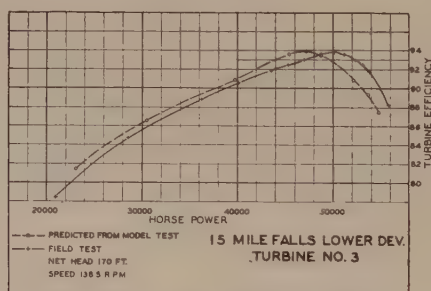


FIG. 15. — TURBINE TEST CURVES

has been installed. There are the usual head and tailwater staff gauges, and, in addition, indicating float gauges for head and tailwater are installed with the indicators on the switchboard. "Winter" piezometers have been installed in the turbines, but are used for check purposes only at the present time. Discharge indications of the turbines are obtained from vane piezometers of our own design, which were calibrated at the time of the test of the turbine. These piezometers have openings on the entering edge of the speed ring vane, and on the side of the vane. A total differential of about 24 feet of water was obtained from these piezometers at full load on the machine for metering purposes. Pressure pipes from these piezometers are led to an electrical transmitting apparatus. Electrical indicating, recording and totalizing meters of turbine discharge are mounted on panel extensions adjacent to the generator field panel at each generator pedestal.

Concrete

A supply of desirable concrete aggregates was found but a short distance from the site. A large hill of trap rock provided a desirable quarry for the coarse aggregate, and a near-by deposit of sand provided the fine aggregate. This sand proved to be rather fine, the fineness modulus varying from 2.0 to 2.7, but the mineralogical composition was excellent. As a result of studies it was decided that although the use of this sand would entail the use of additional cement, it would be more economical than to attempt to ship in sand from other sources. The trap rock proved to be very hard, tough and abrasive, with consequent high production cost and wear on equipment. The maximum size of stone used was 3 inches.

Concrete was mixed at a central mixing plant in a battery of four one-cubic yard mixers located beneath storage bins into which the materials could be dumped directly from material trains. Cement was obtained from six different manufacturers to assure continuity of supply, and was largely shipped in bulk. Storage in two 2,500 barrel silos was provided for this bulk cement from which belt conveyors led to the mixer bins. Proportioning was accomplished by weighing the cement; measuring the stone in batcher bins; and sand and water by a somewhat modified inundation system. Hourglasses were installed at each mixer to assist in timing the period of mixing, which was specified at one and one-half minutes minimum. The mixed concrete was dumped into derrick buckets and transported on flat cars by standard gauge gasoline locomotives to the point of use. All concrete was placed with derricks, except in such forms as were too narrow to admit manipulation of buckets. Here the concrete was placed by the use of very short movable sections of "elephant trunk" equipped with a hopper at the upper end.

In the case of some of the concrete it proved necessary to transfer it from hoppers in which it was transported from the mixer plant to derrick buckets on another track level. This transfer was made by dumping into stationary hoppers and thence into derrick buckets with some attendant remixing from the process. The resulting benefits to the concrete were especially noticeable. The journey from the mixing plant resulted in some settlement of the concrete to the bottom of the receptacle, with consequent rise of water to the surface. After such remixing the concrete was especially uniform, and of a most desirable consistency. The proportions for concrete were fixed by a field lab-

oratory at the mixer plant. This laboratory was completely equipped with testing apparatus and storage room, and even had a small compression machine where 6-inch cylinders could be broken on the job. The specifications called for two grades of concrete in general based on strength at twenty-eight days; 2,000 pounds for the mass structures, and 3,000 pounds where water or weather exposure was especially severe. The proportions varied from time to time with variation in the aggregates, but the average cement content for the entire job was about 1.3 barrels per cubic yard for 2,000 pounds concrete, and 1.7 barrels per cubic yard for 3,000 pounds concrete. Special care was taken in cleaning laitance from the tops of all pours while the concrete was still green. In addition, keys and copper water stops were used at joints to insure water tightness. Customary precautions for curing and protection against freezing of green concrete were carefully observed.

Organization

The contract with the Edison Electric Illuminating Company of Boston called for the initial delivery of power from the Fifteen Mile Falls Development on October 1, 1930. After a month of tuning up and testing out, at 10.30 A.M., September 30, 1930, the Fifteen Mile Falls Lower Development was placed in operation.

The work was carried out for the Grafton Power Company, part of the New England Power Association, by the Connecticut River Development Company as constructors, associated with which was the construction organization of Fraser-Brace Engineering Company, Incorporated. All designs and plans for development were made by the New England Power Construction Company, the predecessor of the New England Power Engineering and Service Corporation, the present service organization of the New England Power Association. Geological investigations were under the direction of Irving B. Crosby, consulting geologist of Boston. Albert S. Crane of New York and Chas. T. Main, Incorporated, of Boston were retained as consulting engineers for the Grafton Power Company. The Public Service Commissions of both New Hampshire and Vermont appointed consulting engineers to approve the structures for the twin States.

FIFTEEN MILE FALLS LOWER DEVELOPMENT — LIST OF EQUIPMENT

EQUIPMENT CLASSIFICATION

1. Hydraulic Generating Equipment:

- (a) Water wheels: 4, S. Morgan Smith Company, vertical, single runner, Francis type, $139\frac{1}{2}$ " diameter, each 53,750 h. p. at 170 ft. head, 138.5 r. p. m.
 - 1. Scroll cases: 4, S. Morgan Smith Company, riveted plate steel spirals $14'-0"$ inlet diameter, plate thickness $\frac{5}{8}"$ to $1\frac{1}{8}"$.
 - 2. Draft tubes: 4, S. Morgan Smith Company, elbow type, formed in concrete substructure, riveted $\frac{1}{2}"$ steel plate lining in upper part.
- (b) Governors: 4, S. Morgan Smith Company actuator type, 190,000 ft. lbs. capacity. Head motor driven by 6.92 cycle, 150 volt, 3 phase current from pilot exciter slip rings.
- (c) Governor oil pumps: 4 screw pumps, Quimby Pump Company, each 300 g. p. m.

2. Water Control Equipment:

- (a) Intake gates: 2, Philips & Davies, Inc., Broome gates, 19' wide x $29' 10\frac{1}{2}"$ high, each with 120 ton electric traveling hoist. Hoisting speed, 2.3 ft. per min. Travel speed, 20 ft. per min.
- (b) Intake racks: 4, McClintic-Marshall (supports) and Lyons Iron Works, $4\frac{1}{2}"$ x $\frac{3}{8}"$ round edge bars, $3\frac{5}{8}"$ centers. Area of racks, per unit, 2,290 sq. ft.
- (c) Rack rake: 1, Newport News Shipbuilding and Drydock Company, $15' 5"$ rake.
- (d) Penstocks: 4, Chicago Bridge and Iron Works, Inc., each 19' diameter, tapering to 16' diameter at end of elbows, 150 ft. long, plate thickness, $\frac{9}{16}"$ to $\frac{3}{8}"$.
- (e) Inlet valves: 4, S. Morgan Smith Company, 16' diameter Dow disc-arm valves, operated by 30" hydraulic cylinders.
- (f) High pressure sluice valves: 2, S. Morgan Smith Company 9' diameter, Dow disc-arm valves, operated by electric motors through worm geared, screw stem, hoisting units.
- (g) Low pressure sluice gates: 6, I. P. Morris & DeLaVergne, Inc., 7' x 9' cast iron sliding gates, operated by pressure cylinders. Operating fluid, water treated with potassium bichromate.
- (h) Emergency gate for high head and low head sluices: 1, Philips & Davies, Inc., Broome gate, 10' x 10'.
- (i) High pressure sluice racks: 2, Palmer Steel Company, 4' x $\frac{3}{4}"$ bars, 6" centers. Area of racks per sluice, 1,130 sq. ft.
- (j) High pressure sluice liners: 2, D. M. Dillon Boiler Works, 10' diameter x $66' 7\frac{5}{8}"$ long, $\frac{3}{8}"$ riveted steel plate.
- (k) Flashboards: 306' of pin type boards 6' high; pins 3" extra-heavy pipe; 153' spaced 2.48 ft. centers, and 153' spaced 1.97 and 1.96 ft. centers; 539' 3" of stanchion type boards 8' high, stanchions 10" C. B. 23 lbs., 16' $7\frac{1}{2}"$ long, spaced 5.92' centers.

3. Electric Generating Equipment:

- (a) Generators: 4, Westinghouse Electric and Manufacturing Company, each 39,000 kva., 138.5 r. p. m., 13,800 volt, 3 phase, 60 cycle. Combination Kingsbury thrust bearing and guide bearing. Umbrella type rotor spider.

3. *Electric Generating Equipment* — Concluded.

- (b) Exciters: 4, Westinghouse Electric and Manufacturing Company, each 210 kw., 250 volt. Direct connected to generator.
- (c) Pilot exciters: 4, Westinghouse Electric and Manufacturing Company, each 25 kw., 250 volt. Equipped with slip rings which furnish current for driving governor head motors. Direct connected to generator.
- (d) Motor driven exciter and pilot exciter: 1, Westinghouse Electric and Manufacturing Company: exciter, 210 kw., 250 volt; pilot exciter, 3 kw., 250 volt. Both direct connected to 325 h. p., 3 phase, 2,300 volt, 900 r. p. m. induction motor.

4. *13,800 Volt Switching Equipment:*

- (a) Generator oil switches: 4, General Electric Company, type FH-206, 15,000 volt, 2,000 amp., 3 pole single throw, motor operated.
- (b) Disconnecting switches: 28, Electric Power Equipment Corp., 15,000 volt, 2,000 amp., single pole single throw, hook stick operated.
- (c) Potential transformers: 24, Westinghouse Electric and Manufacturing Company, 13,800 volt—115 volt, 200 va.; 16 with fused primaries, 8 unfused.
- (d) Current transformers: 100, Westinghouse Electric and Manufacturing Company: 12, 3,000 to 5 amp.; 48, 2,000 to 5 amp.; 4, 2,000 to 5 amp. with double secondary; 24, 1,000 to 5 amp.; 12, 30 to 5 amp.
- (e) High speed rheostatic generator voltage regulator equipment, Westinghouse Electric and Manufacturing Company.
- (f) Automatic frequency and load control equipment, Warren Telechron Clock Company.
- (g) Control battery: 2, Electric Storage Battery Company, EOGO-7, 60 cells, 125 volt.
- (h) Battery charging set: 1, Rochester Electric Products Corp., Diverter pole generator set $3\frac{1}{2}$ kw., 125 volt, driven by 5 h. p., 3 phase, 110 volt induction motor.

5. *Transforming Equipment:*

- (a) Transformers: 14, General Electric Company, 60 cycle, 13,000 kva., 230,000 volt Y-13,400 volt, single phase outdoor type, water cooled.

6. *230 Kv. Switching Equipment:*

- (a) Oil circuit breakers: 7, General Electric Company, type FHKO-139, 230 kv., 800 amp., 3 pole single throw, motor operated.
- (b) Disconnect switches: 23, Electric Power Equipment Corp., 230 kv., 800 amp., 3 pole single throw; 22 motor operated, 1 hand operated.
- (c) Lightning arrester: 1, General Electric Company, 230 kv., 3 phase Thyrite arrester.
- (d) Control battery: 1, Electric Storage Battery Company, EOGO-13, 120 cells, 250 volt.
- (e) Battery charging set: 1, Rochester Electric Products Corp., diverter pole generator set 5 kw., 250 volt, driven by $7\frac{1}{2}$ h. p., 3 phase, 220 volt induction motor.

*7. Local Service Equipment:**(a) Transforming equipment:*

1. Transformer: 1, General Electric Company, 60 cycle, 12,500 kva., 230,000 volt Y-33,000 Y/66,000 Y-2,300 volt, 3 phase, outdoor type, water cooled.

(b) 66 kv. switching:

1. Oil circuit breakers: 4, Westinghouse Electric and Manufacturing Company, type G-22, 73 kw., 600 amp., 3 pole single throw, frame mounted, solenoid operated.
2. Lightning arrester: 1, General Electric Company, 66 kv., 3 phase Thyrite arrester.

(c) 2,300 volt switching:

1. O. C. B. houses: 5, Westinghouse Electric and Manufacturing Company, type B-20 breakers, 7,500 volt; 1, 800 amp., 4, 400 amp., equipped with necessary relays and metering equipment.

8. Station Service Electrical Equipment:

- (a) Transformers:*
- 5, General Electric Company: 4, 60 cycle, 500 kva., 13,800 volt-460 volt, 3 phase, self-cooled; 1, 60 cycle, 500 kva., 2,300 volt-460 volt, 3 phase, self-cooled.

(b) 440 volt bus:

1. Oil circuit breakers: 14, Westinghouse Electric and Manufacturing Company: type F-22; 5, 800 amp.; 2, 600 amp.; and 7, 400 amp., 3 pole single throw.
2. Potential transformers: 16, Westinghouse Electric and Manufacturing Company: 460 volt-115 volt, 100 va.; 5 unfused, 11 fused.
3. Current transformers: 40, Westinghouse Electric and Manufacturing Company: 22, 800 to 5 amp.; 4, 600 to 5 amp.; 2, 400 to 5 amp.; 8, 200 to 5 amp.; 4, 100 to 5 amp.

(c) 2,300 volt bus:

1. Oil circuit breakers: 4, Westinghouse Electric and Manufacturing Company, type B-16, 400 amp., 3 pole single throw.
2. Current transformers: 8, Westinghouse Electric and Manufacturing Company: 4, 300 to 5 amp.; 4, 150 to 5 amp.

9. Station Auxiliaries:

- (a) Power house cranes:*
- 2, Cleveland Crane and Engineering Company, each 115-ton capacity with 15-ton auxiliary, 60' 10" span. Main hoist speed, 4 ft. per min. Auxiliary hoist speed, 20 ft. per min. Trolley travel speed, 20 ft. per min. Bridge travel speed, 40 ft. per min.
-
- (b) Transformer crane:*
- 1, Philips & Davies, Inc., 90 tons, 30' 0" span. Hoist speed, 2½ ft. per min., 195' lift. Trolley travel by hand.
-
- (c) Air compressors:*
- 2, Ingersoll-Rand Company: 1, 9' x 8", class E R-1 single stage, 173 c. f. m., 100 lbs., belt driven by Westinghouse motor; 1, 2-stage type 30, 20 c. f. m., 200 lbs., belt driven by General Electric motor.
-
- (d) Transformer cooling water pumps:*
- 2, Allis Chalmers Manufacturing Company, 3" x 2½", SJH centrifugals, each 350 g. p. m., 150 ft. head, direct connected to 3,500 r. p. m. Allis Chalmers induction motor.

9. *Station Auxiliaries* — Concluded.

- (e) Booster pumps for inlet valves: 2, Worthington Pump and Machinery Corp., 2", V-1 centrifugals, each 150 g. p. m., 405 ft. head, direct connected to 3,450 r. p. m. Westinghouse motor.
- (f) Pumps for low pressure sluices: 2, Worthington Pump and Machinery Corp., 2", 2-stage "S D" centrifugals, each 150 g. p. m. at 300 lbs., direct connected to 3,450 r. p. m. Westinghouse motor.
- (g) Transformer oil pump: 1, Viking Pump Company, 1½" model ZKM, 30 g. p. m. at 125 lbs., direct connected to Westinghouse motor.
- (h) Sump pumps: 2, Worthington Pump and Machinery Corp., Axiflo: 1, 150 g. p. m. and 1, 270 g. p. m. at 7½' head, direct connected to General Electric motors.
- (i) Lubricating oil pump: 1, Viking Pump Company, 1½" model ZK, 35 g. p. m. at 30 lbs., gear driven by Westinghouse motor.
- (j) Passenger elevator: 1, F. S. Payne Company, automatic passenger elevator, capacity 2,500 lbs. Speed, 200 ft. per min.

10. *220 Kv. Switching Auxiliaries:*

- (a) Power transformers: 6, General Electric Company, 60 cycle, 50 kva., 2,300-440 volt, single phase.
- (b) Lighting transformers: 2, General Electric Company, 60 cycle, 37½ kva., 2,300-220/110 volt, single phase.

Discussion

ARTHUR C. EATON: * Mr. Bliss has told you that it was attractive to develop the Fifteen Mile Falls section of the Connecticut River in two plants of about equal head. This word "attractive" means, of course, several things, but I think it is of interest that the dominant factor in deciding on a two-plant development for this section of the river was the scarcity of dam sites. We investigated the possibility of making this development in a single full-head plant, but that was found to be unattractive. In investigating for dam sites the only ones found which were at all attractive were the two adopted for the two stage development. Of course, there were other things about this two stage development which were attractive, but the two dam sites were the dominating factors.

I think the question might well be asked why we developed the lower site first rather than the upper site. There were several good reasons why the Upper Development should have been built first, and it may be of interest to know why the lower one was given preference. In the first place, the upper site would have brought with it a storage

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of 5,000,000,000 cubic feet, about four times the amount at the Lower Development — with a 40 foot drawdown. Then, again, with the upper plant built, the water control in building the lower plant would have been much simplified; and still again, the upper plant could have been built with less ice trouble than the lower plant, and in turn would have eliminated all ice trouble in the construction of the lower plant.

These factors were all recognized, and up to late in the spring of 1928 we had expected to develop the upper site first. During all the preliminaries the one fixed quantity in the equation was the date of completion, October 1, 1930. As time slipped along into midsummer the element of time of completion loomed more important than any other consideration. The upper plant carried with it a 3,000,000 yard earth dam and difficult foundation conditions. The lower site held out the choice of either an earth dam of good size or the use of almost 100 per cent concrete construction. When authorization came through in August with a great big tag, "Finish October 1, 1930," we realized that the only thing to do was to go ahead with the lower site on a concrete construction basis.

WILLIAM F. UHL: * Since I arrived here this evening, several have asked if I would say something about the concrete at Lower Fifteen Mile Falls, but I believe it would be better to wait until the concrete has seen several years of service before we talk much about it.

However, I will say that I believe as much care was used on this job as has ever been taken on similar work to produce a really good concrete. At this time I would offer only one suggestion for a change in the manner of making the concrete at Lower Fifteen Mile Falls. That suggestion is based on something I learned on a more recent job where an attempt was made to place concrete as dry as possible, and where the construction forces seem to have had difficulty in placing the concrete. On that job I suggested that the mixing time be increased from one and one-half to two minutes, with the idea of improving the workability of the concrete. The construction forces said they could not do that because it would interfere with the progress of the work, but they tried it out, and it was surprising to see the difference in the workability of that concrete. It was later admitted that the increased mixing time did not in any way interfere with the progress of the construction work, and no more difficulty was had with the placing of the concrete.

The one suggestion I have to offer is that on work of this kind the concrete be mixed for at least two minutes. This improves the

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workability very materially, and also improves the quality. The extra cost is negligible, and with a proper construction plant the work will not be slowed up.

The development of the Fifteen Mile Falls on the Connecticut River has been under consideration for many years, but it was impossible to work out a practicable combination of suitable market and engineering economics that would indicate a commercial success, until a few years ago.

A suitable market in this case meant, first, a large market, and secondly, a market being supplied in large measure by steam plants which the water power could supplement rather than replace.

It can be shown that in many cases the lowest cost power is the result of a suitable combination of steam and water power. Much of the water power developed today could not be developed economically except in combination with steam power.

This is true because in many cases water power plants can carry peak loads at less cost than steam plants, and steam plants can carry base loads at less cost than water power plants.

To accomplish this, a water power plant must be able to concentrate its major output for use in a relatively short period of the total operating time.

Consequently, the engineering economics of the whole Fifteen Mile Falls situation demanded that the available power be developed with a maximum of pondage and storage, which meant that the total fall must be utilized with as few plants as possible, which, in turn, limited the locations in which the necessary structures could be built.

The final decision to develop practically the whole available fall with two plants called for exceptionally large and unusual structures, the size of which alone resulted in interesting problems.

Usually, when we use the term "falls" in relation to a river, we think of a precipitous drop in a river bed over which the flow of the stream falls in wild abandon. Fifteen Mile Falls is not such a falls, but is a series of rapids extending over a distance of approximately fifteen miles, in which distance the river has a difference in elevation of nearly 350 feet.

In all this distance there is not a single natural dam site.

As with so many of our rivers in New England and New York, the present river bed of the Connecticut River in this locality now flows at a higher elevation than in preglacial times, and its present bed meanders back and forth over the glacial material which has filled the original stream bed. At no point can rock be found at both banks and across

the bed of the stream at reasonable distances below the surface, and in most cases economical construction prevents founding all the structures on rock. The glacial overburden is seldom uniform over any great distance, and even after numerous test pits are dug and borings made, it is still difficult to closely determine its character, particularly with reference to its imperviousness.

Consequently the economic development of such a situation demands exhaustive study and extreme care. The designers of the Lower Fifteen Mile Falls Development were confronted with the problem of designing structures which could be safely and economically built on a site which was distinctly not a natural dam site, rather than with the more usual problem of adapting fairly well known structures to a natural dam site.

The cost of a development of this kind must be kept within certain limits, since the power developed must compete with steam power produced by modern tidewater steam plants, yet safety and durability must be the first considerations.

It is always important that engineers design and build their structures safely and at minimum cost; but in most cases they are not so limited in the choice of the sites on which they may build, and the element of cost is not so dominant. In the case of this water power development, the first cost largely fixed the cost of the product for all time, whereas in the case of most other undertakings the cost of the product depends more upon labor, materials and management than upon the first cost of the necessary structures and equipment.

Our thanks are due Mr. Bliss for presenting his excellent paper on this subject, in which we here in New England are naturally very much interested. He and his associates are to be commended for the thorough manner in which they have mastered the various problems and difficulties connected with this work and for the successful completion of the job in schedule time.

Much credit is due the officials of the New England Power Association, whose courage in undertaking the development of these Fifteen Mile Falls in the face of many economic and legal difficulties will undoubtedly be of lasting benefit to the people and industries of New England.

IRVING B. CROSBY: * Mr. Bliss has referred briefly to the geological conditions at Fifteen Mile Falls, and it may be of interest to describe some of the geological features more fully.

The most interesting practical problem is concerned with the gla-

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cial deposits. Before the ice age the land stood higher than at present. The streams had eroded deep valleys, had begun to widen them, and were meandering on the floors of these valleys. An uplift caused the streams to renew the down-cutting and to entrench themselves in winding gorges. Evidence of these gorges cut in the floors of preglacial valleys has been found at many dam sites in New England, New York and Quebec. The erosion of these gorges was cut short by the advance of the great ice sheet which covered all of New England. When the ice finally melted away, enormous quantities of glacial drift were deposited over the country, partly filling the valleys. The glacial drift consisted of the unsorted and unstratified boulder clay, which was deposited directly from the ice, and stratified deposits of clay, sand and gravel, which were laid down in water.

When the Connecticut River again took its course to the sea after the disappearance of the ice, it followed its old valley, picking its way over the uneven surface of the glacial drift, but the gorge which had been cut in the floor of this old valley was deeply buried under the glacial drift, and therefore the new course had no relation to the old channel. The new stream meandered at a higher level, crossing and recrossing the buried gorge. After the stream had cut down through the glacial drift, in places it cut into ridges of rock at the side of its old valley, and it is at such a place that the lower dam at Fifteen Mile Falls is located.

As Mr. Bliss explained, the buried gorge is on the New Hampshire side of the river with its center about 1,300 feet from the middle of the river. Rock is exposed in many places on the Vermont side and rises about 10 feet above the river on the New Hampshire side; then, as shown by the borings, it continues nearly level for about 800 feet before it descends into the buried gorge.

At the site of the Upper Dam, 8 miles upstream the buried gorge is on the Vermont side of the river, and there is ledge on the New Hampshire side. The preglacial gorge is deeper here than at the Lower Dam, and the glacial deposits which fill it are more complex. At McIndoes Falls, 7 miles downstream, the conditions are similar to those at the Lower Dam. The river flows over ledge and there are numerous ledges on the Vermont side. The preglacial channel is buried under a sand terrace on the New Hampshire side of the river.

The bluff on the New Hampshire side at the Lower Dam is composed of glacial deposits above the first 10 feet, which is rock. Resting on the rock are irregular lenses of gravel, and above them a layer of glacial till or boulder clay 60 to 80 feet thick. Above the boulder clay

is a bed of sand varying from a few feet to over 20 feet in thickness. On this sand is a second layer of boulder clay, showing that there was a re-advance of the ice. This upper glacial till is sandier and contains less clay and fewer stones than the lower till, and has therefore been referred to in the reports as modified till to distinguish it from the lower till or boulder clay. Above this upper till there is in places a layer of clay and then sand to the top of the bluff.

As was explained by Mr. Bliss, it was not considered that the gravel on the ledge would cause serious seepage, because the discontinuity of the lenses minimizes seepage through them. The boulder clay is a dense and impervious material which is excellent for the foundations of an earth dam or for use in an earth dam, and the clay is also impervious. The upper sand is so near the top of the dam that it was an easy matter to put a cut-off through it into the impervious clay. The lower sand was studied thoroughly and the location and thickness determined by borings and many test pits, and permeability tests were made on samples in the laboratory. As a result of these studies it was decided that, with the design adopted for the earth embankment, there would be no serious seepage, and subsequent events have shown this to be the case.

The geological conditions at Fifteen Mile Falls are similar in a broad way to those found at many other dam sites in New England, but the details are different.

ALFRED O. DOANE: * Something was said about electric prospecting tests for rock. Can some one tell us anything about that?

MR. CROSBY: We made some surveys by electric prospecting methods when the drilling became too slow and expensive on account of numerous boulders. Electrical prospecting was developed originally in the mining industry and also in studying the geological structure in oil fields. As far as I can learn, it had never been used in connection with dam site studies until its application at Fifteen Mile Falls in April, 1928. After looking into the matter, and talking with representatives of different companies that had been doing electrical prospecting in mining and oil fields, we decided it might be successful here and tried it out. A demonstration was arranged where the location of rock was known from borings, and this test being successful the method was used extensively in connection with the drilling campaign.

By this electrical method one gets a quick and approximate determination of the depth to rock. The method depends upon the fact

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that different materials in the earth have different degrees of resistivity to the passage of an electric current. Usually the overburden is much less resistant than bed rock, and when that is the case the depth to rock — the contact between the resistant and less resistant materials — can be determined fairly accurately.

JOHN J. CAMPOBASSO: * What is known about the seepage from the old stream bed into the present stream bed? Were any tests made to determine that?

MR. BLISS: No tests have been carried out on that. If there is any such seepage it would be over such a tremendous amount of area that it would really be of no significance.

MR. CROSBY: While we have no direct information on it, it is probable that the old stream channel is largely filled with boulder clay, but there may be a little water seeping through it. However, no leakage from it has been detected.

PROF. H. K. BARROWS: † It is of interest, after hearing Mr. Bliss's paper, to look back somewhat and see what has been accomplished in the last few years in New England by the New England Power Association in the way of large water power developments, which have included the following:

Date	PLANT	Head (Feet)	Horsepower Capacity
1924-25	Davis bridge	360	60,000
1928	Bellogs Falls	60	60,000
1930	Fifteen Mile Lower	165	200,000
1931	McIndoes	30	15,000
	Total	615	335,000

A total of 615 feet of head and 335,000 h. p. of capacity has thus been developed in about seven years.

When the Upper Fifteen Mile Falls has been completed there will be upwards of half a million horsepower and some 760 feet of head developed by these five plants. Certainly this is a large block of water power to be developed here in New England in about a decade, assuming that conditions will be such that Upper Fifteen Mile Falls plant

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† Consulting Engineer, Boston, Mass., and Professor of Hydraulic Engineering, Massachusetts Institute of Technology.

will come along so that the whole program will be completed by about 1934.

This society has also been very fortunate in having had presented before it the excellent papers on these various plants, the first, by Mr. A. C. Eaton, on the Davis bridge development: * the second, by Mr. E. A. Dow on that at Bellows Falls: † and now the admirable paper we have listened to this evening by Mr. Bliss. We have thus an unusually full and valuable record of these interesting developments.

One of the most interesting features of this plant to me was the fact that 10 feet of added head could be developed by tailrace excavation at a less cost per horsepower than that of the main development.

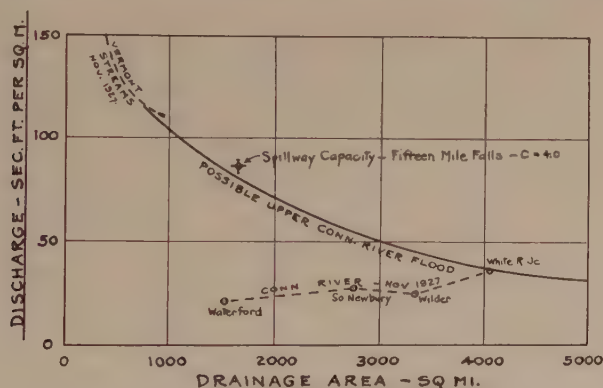


FIG. A. — POSSIBLE UPPER CONNECTICUT RIVER FLOODS

— reflecting the care taken by the designing engineers to get the best possible results.

In studying the necessary capacity of the spillway, it can be looked at from several different angles. If we take Weston E. Fuller's flood formula, using a co-efficient of 60, a thousand-year crest flood would give about 90,000 second feet. For 10,000 years — a very rare flood — the crest discharge would be about 110,000 second feet. In checking up the possible flood flow I also made use of information obtained from the New England flood of 1927, during which the flow was very high on the Connecticut River at White River Junction, below the junction of White River. In fact, at and below that point on the Connecticut River it exceeded all other known floods.

* Journal, Boston Society of Civil Engineers, January, 1925.

† Journal, Boston Society of Civil Engineers, March, 1930.

This study is shown in Fig. A, where, in addition to unit flows at various points on Connecticut River in 1927, is shown at the upper left by dotted line the unit flows reached upon various Vermont streams, none over 1,000 square miles in drainage area. Using the unit flow at White River Junction and the dotted curve for areas under 1,000 square miles, a limiting curve is obtained which is probably close to the maximum likely flood. As will be noted from Fig. A, the spillway capacity at Fifteen Mile Lower Development somewhat exceeds the requirements of this curve.

A study of power house size for the four plants on the Deerfield and Connecticut rivers shows the following (including for comparison certain other plants):

POWER HOUSE — AREA AND VOLUME

PLANT	Head (Feet)	Horsepower Capacity	POWER HOUSE	
			Square Feet per Horsepower	Cubic Feet per Horsepower
Davis bridge	360	60,000	.11	5.1
Sherman	78	10,000	.26	8.3
Bellows Falls	60	60,000	.16	6.2
Fifteen Mile Lower	165	200,000	.11	6.7
McIndoes	30	15,000	.42	12.5
Turners Falls	56	63,000	.37	16.0
Tallulah Falls (Ga.)	580	85,000	.22	17.5

The compact design of these later plants of the New England Power Association is evident, especially the Fifteen Mile Falls Lower plant. In comparing the above, it must be kept in mind that head is important, the higher head plants in general tending toward lower values of area and volume per horsepower.

This development of the upper Connecticut River might well be the initial step in a comprehensive plan for the storage-power development of this great river, the largest in New England.

There are at present on the main river the following developments:

PLANT	Head (Feet)
Fifteen Mile Lower	165
McIndoes	30
East Ryegate	25
Wilder	35
Bellows Falls	60
Vernon	35
Turners Falls	60
Holyoke	60
Total	470

There remain to be developed:

PLANT	Head (Feet)
Upper Fifteen Mile	150
Hartland	20±
Windsor Locks	30
Total	200

There is therefore a total of nearly 700 feet of head on the main river which is already over two-thirds developed.

On the *Vermont side* the many tributaries of the Connecticut afford some excellent opportunities for storage-power developments. These streams have all been carefully studied and projects laid out by the Advisory Committee of Engineers on Flood Control of Vermont.*

On the *New Hampshire side* no systematic investigation has been made, but numerous opportunities for storage development are available.

In *Massachusetts* the Deerfield River is already well developed, as regards storage, by the New England Power Association. There are also some further opportunities for storage on Westfield and Millers rivers.†

Considering only such storage reservoirs as have been either defi-

* Report of this committee to Governor John E. Weeks, dated December 15, 1930.

† Report upon Water Power, Massachusetts Waterways Commission, 1918.

nately planned or constructed on the main river and in Vermont, the following would be included:

PROJECTS	Storage Capacity (Billion Cubic Feet)
Connecticut River—Fifteen Mile Falls and Connecticut Lakes (5.4 billion cubic feet now developed)	10.4
Vermont tributaries of Connecticut River, proposed storage	33.6
Deerfield River, now developed	7.3
Total	51.3

The effect of this storage on the low water flow of the Connecticut River at various points is shown in the following table:

CONNECTICUT RIVER—EFFECT OF STORAGE ON LOW WATER FLOW

POINT ON MAIN RIVER	Drain- age Area (Square Miles)	STORAGE (BILLION CUBIC FEET)			Storage (Million Cubic Feet per Square Mile)	MINIMUM (95 PER CENT) FLOW (c. f. s.)	
		Main River	Vermont (includ- ing Deer- field River)	Total		Present Condi- tions	With Storage as in Column 5
1	2	3	4	5	6	7	8
Lower Fifteen Mile Falls	1,650	10.4	4.0	14.4	8.7	500	1,600
McIndoes	2,200	10.4	7.8	18.2	8.7	700	2,100
Bellows Falls	5,300	10.4	25.7	36.1	5.0	1,500	4,000
Vernon	6,300	10.4	33.6	44.0	7.0	2,000	5,500
Turners Falls	7,100	10.4	33.6	44.0	6.2	2,500	5,900
Holyoke	8,000	10.4	41.3	51.3	6.5	3,000	7,000

The above figures of effect upon flow are based only upon approximate studies, but are believed to be reasonable. They indicate the great opportunities which are available for building up the low water flow of the Connecticut River.

Keeping in mind that more storage is also available in New Hampshire and Massachusetts, it will be seen that the Connecticut River can be made one of the best power streams in the country, and at the same time its flood tendencies can be largely eliminated.

MR. KENNETH C. REYNOLDS: * It is of interest to learn of the large use of models in connection with the Fifteen Mile Falls development. I was particularly interested in the hydraulic models. While these were fundamentally made for studying the safest and most satisfactory way of developing the structures, I wonder if actually any material saving in cost developed by the use of these models.

MR. BLISS: I think that would be very interesting to investigate, but it is difficult to say what savings resulted. I am sure there was a saving in the stripping of the overburden on the Vermont side below the spillway. At Worcester there was a model constructed of the penstock and the penstock intake, as a result of which we were able to eliminate one elbow in the penstock and reduce the deflection of the other. This, together with the buttress design, permitted the concrete structure to be carried to a much more advanced point before it was complicated by the erection of the penstock than otherwise would have been the case. There was a material reduction in the amount of concrete in the retaining wall also. We were able to construct shallower draft tubes than otherwise could have been designed, resulting in reduced rock excavation for them.

MR. EDWARD S. LARNED: † What does the cement factor per cubic yard of concrete mean in volume? That is, how would you describe that concrete in the usual terms of cement, sand and water?

MR. BLISS: The proportions varied from time to time as the nature of the aggregates varied. The coarse aggregate was fairly constant, but the sand was fine and variable. The proportions resulting were variable, but as I remember it the mix for 2,000 pounds concrete was about $1 : 2\frac{1}{2} : 4\frac{1}{2}$.

MR. HARSCH: ‡ I would like to inquire if there is any log-driving now in that section of the Connecticut River.

MR. BLISS: In former years there was a tremendous amount of log-driving on the Connecticut River. In the season of 1892 I think about 20,000,000 feet of lumber were cut out at the sawmill that existed on the Vermont side at McIndoes, but it was abandoned in 1907. At Bellows Falls, Vernon and below, the drives continued until 1913 or 1915. In recent years there has been no log-driving on that portion of the Connecticut. The design has been so carried out that in case of log-driving it can be accommodated at Fifteen Mile Falls.

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‡ Assistant Engineer, Morton C. Tuttle Company, Park Square Building, Boston, Mass.

MECHANICAL AND HYDRAULIC FEATURES OF McINDOES FALLS DEVELOPMENT OF THE GRAFTON POWER COMPANY—PART OF THE NEW ENGLAND POWER ASSOCIATION

HARRY E. POPP *

(Presented at a meeting of the Boston Society of Civil Engineers, January 27, 1932)

THE McIndoes Falls Development of the Grafton Power Company is located at a low natural falls on the Connecticut River about seven miles below the Lower Fifteen Mile Falls Development. The intervening river is relatively flat, and a drawdown of 6 feet provides 2,800 acre feet pondage, so that the economic development of 5,000 c. f. s. under an average gross head of 27 feet is possible. The plant has an installed capacity of 13,200 kva. in four units.

There is nothing spectacular about the McIndoes Falls Development. It is in general a typical low-head plant. It is, however, interesting because it is the first hydroelectric plant in New England in which automatic adjustable blade Kaplan turbines are used. This type of turbine is of European origin, and its acceptance in this country is of comparatively recent date. While the advantages were self-evident, the accompanying objections were carefully considered, and a decision to adopt the adjustable blade turbines for McIndoes Falls was reached only after a detailed analysis of the design and thorough study of the possibility of operating difficulties. It is gratifying to report, after nearly a year's operation, that expectations as to performance have been fully realized, and that no troubles in operation have been encountered which are attributable to the adjustable blade design.

GENERAL LAYOUT

Fig. 1 shows the general layout of the development. In addition to the turbine discharge, the plant has been designed to pass a total flood flow of 65,000 c. f. s. The 300 feet of spillway section, with 6 feet

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pin type flashboards, will pass 15,000 c. f. s. The three tainter gates, 24 feet wide by 25 feet high, and the skimmer gate, 12 by 13 feet, will pass about 25,000 c. f. s. The 100-foot stanchion flashboard section will pass about 25,000 c. f. s.

SPILLWAY AND GATES

The design of the spillway crest and gates is shown in greater detail in Fig. 2. The pin type flashboards are supported on half of the crest by 3-inch standard pipe pins spaced on 2-foot centers. On the

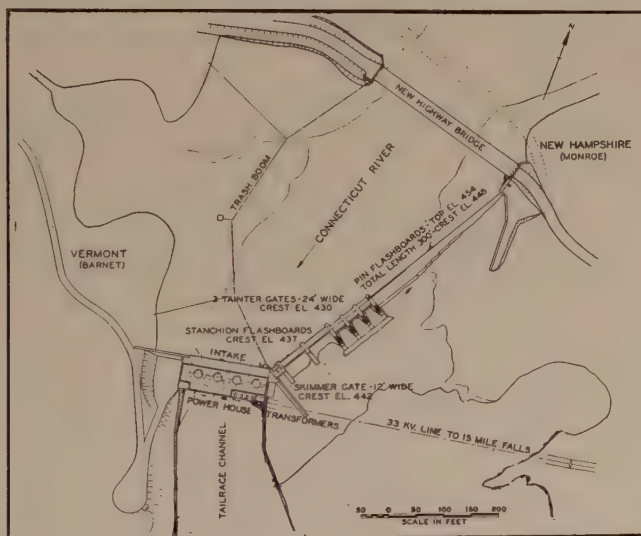


FIG. 1. — GENERAL LAYOUT OF McINDOES FALLS DEVELOPMENT

other half 3-inch extra heavy pipe pins are used. The standard pins are designed to fail, with resulting loss of the boards, with water 1.9 feet over the tops of the boards. The extra heavy pins are designed to fail with water 2.75 feet over the boards. A 4-ton capacity cableway, with motor-driven hoist, has been provided for handling the pins and boards on this section of the crest. Steel towers on each end of the spillway section support the cableway, the hoist being located on the east bank of the river.

The stanchion type pins consist of 16-inch steel beams on about 5-foot centers resting in cast steel sockets in the crest, and supported at the upper ends by individual release mechanisms attached to the bridge. Under normal operating conditions the boards and stanchions are re-

moved by means of a 2-ton electric mono-rail hoist carried by steel A frames and latticed girders above the pins. The upper ends of the pins are designed to slide vertically in guides to a position clear of the water surface after removal of the boards. The emergency mechanism is designed to release the upper end of the pins by merely a blow from a hammer, in which case both pins and boards are lost.

The tainter gates are of riveted steel construction, with non-parallel arms to prevent difficulties due to the formation of ice between the piers and the arms. Individual 30-ton motor-driven, double-drum hoists have been provided for the operation of these gates. The hoists are

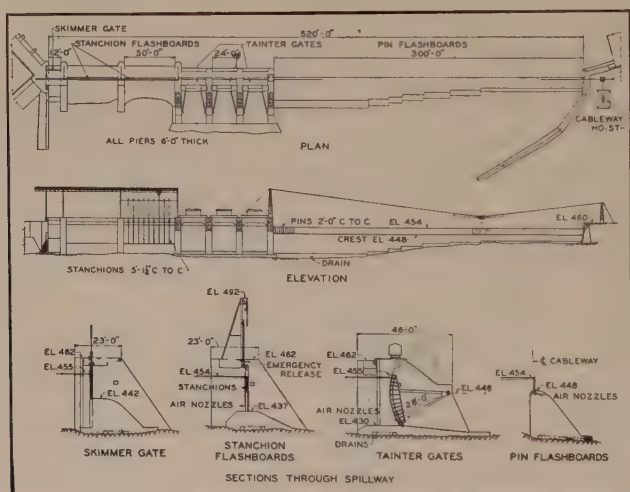


FIG. 2. — SPILLWAY AND GATES PLAN, ELEVATIONS AND SECTIONS

mounted on steel beams spanning the gate openings. A wooden sealing strip is used at the bottom of the gate, and rubber seals at the sides in contact with steel seal plates on the pier faces. Back of these plates space is provided in the piers for electric heaters to prevent freezing at the vertical joints. About 8 kw. per gate has been found to be sufficient in the most extreme weather.

The skimmer gate is of steel, concrete filled, and is designed to open by lowering, permitting trash and ice to pass over the top. A 50-ton motor-driven twin screw hoist is provided for operating this gate. The entire downstream surface of the gate is planed for tight contact with the frame.

Extraordinary provision has been made for the use of compressed air in preventing formation of ice on the tainter gates and flashboards. Air at about 25 pounds per square inch in the supply line from a compressor in the power house is used. On the tainter gates three air nozzles per gate are installed at the bottom, fed through the skin plate from a common header on the downstream face of the gate. This header connects with the supply line on the bridge by means of pipes on the gate arms, and flexible connections at the trunnions. The stanchion type boards are kept free of ice by means of removable nozzles extending below the water surface from the supply line on the bridge. The spillway crest is provided with nozzles on 8-foot centers connected to a

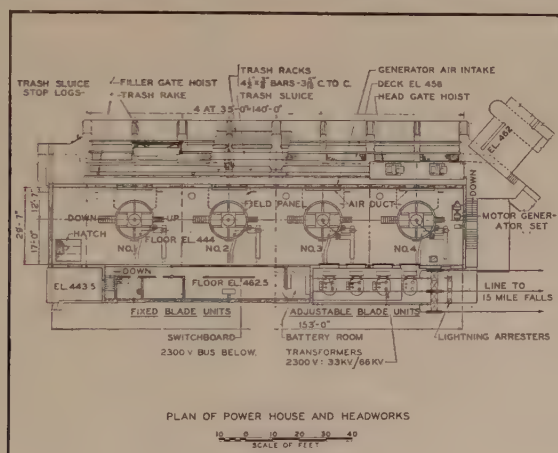


FIG. 3

submerged header on the upstream face of the dam by means of short pipes passing through sleeves in the concrete. Approximately 1 cubic foot of free air per minute is supplied for each 10 feet of crest. The station compressor has a capacity of 100 cubic feet of free air per minute.

POWER HOUSE AND HEADWORKS

The power house and headworks are arranged in plan as in Fig. 3. The units are spaced on 35-foot centers. The intake racks are $4\frac{1}{2}$ by $\frac{3}{8}$ inches round-edged flat bars spaced $2\frac{1}{8}$ inches in the clear. They are designed for full head on one side. A traveling motor-driven rack rake discharges into a trash sluice, which in turn discharges into the skimmer gate sluice. With normal pond level, water

is admitted to the trash sluice by removing the stop logs at one end. When the pond is low, a motor-driven low-head centrifugal pump discharges 750 g. p. m. into the sluiceway. High pressure air for pneumatic rack cleaning is supplied through perforated pipes at the bottom of the intake.

There are two head gates for the plant, each 13 feet 9 inches wide, and 12 feet high, operated by one motor-driven gantry crane with two 25-ton drum hoists. These gates are of the structural steel type, concrete filled. The sealing strips on the gates are of steel. Those on the steel frames are bronze. Both gates are required to close off one unit, and they are traversed from unit to unit as required. Hand-

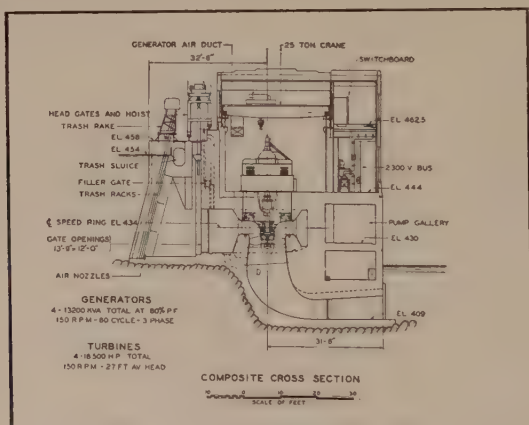


FIG. 4

operated filling gates to equalize the pressure on the main gates have been provided.

In cross section the typical arrangement is as illustrated by Fig. 4.

The power house crane consists of two 12½-ton motor-driven hoists mounted on a single trolley, with sufficient clearance between the hoists to permit the turbine shaft to pass up through when lifting the runner and shaft assembled. This arrangement of crane trolley permits a considerable saving in head room required in the station.

GENERATORS

The generators are of the umbrella, or overhung, type, with the combined thrust and guide bearings located in an oil-filled housing below the rotor. The thrust bearings are of the Gibbs type, having a

capacity of 250,000 pounds. The generators are of welded steel construction throughout.

Cooling air for the generators is taken through louvres on the upstream wall of the power house, and carried through vertical steel ducts on the inside power house wall to a passage under the floor communicating with the turbine pit. Provision has been made to enable outside air to be taken to the generators, or for recirculating the air within the power house.

The usual concrete cover over the horizontal air duct has been eliminated and a 1-inch steel plate substituted, resulting in a minimum thickness of floor slab. Approximately one-third of the generator circumference rests upon this plate, which in turn is supported by I beams resting on the concrete above the scroll case. The plate was carefully designed and securely tied into the generator floor slab by means of both vertical and horizontal anchor bolts to transmit to the concrete structure the torque from the portion of the generator which rests upon it.

Width has been conserved in the power house by the use of a steel plate generator pedestal instead of the conventional concrete design. This design provides sufficient opening to permit the largest turbine piece to be removed. The thrust bearing bridge is supported on a heavy flange in the inside of the steel pedestal. It is removable laterally through openings in the side of the pedestal, so that the latter need not be disturbed if it is necessary to remove any large turbine parts.

TURBINES

The turbines are of the single runner, vertical, propeller type, two having fixed blades, and two having adjustable blades, direct connected to 3,300 kva. generators. Each turbine is designed to pass 1,250 c. f. s. at best efficiency under 27-foot head at 150 r. p. m.

Fig. 5 is a plan at the center line of the turbine speed rings, and shows the general arrangement of the concrete turbine scroll cases and general disposition of the governor pressure equipment and auxiliary apparatus in the pump gallery. The scroll cases are accessible through manholes from the generator floor. Mandoors through the speed ring pedestals provide access to the draft tubes below the runners.

Both the scroll case and draft tube are formed in the concrete substructure. The former is of the "modified" type, with only a portion of the wheel fed from a truly spiral section. The latter is of the elbow type, with one central supporting pier in the horizontal leg. The hori-

zontal portion of the draft tube is shallower at the center than at the sides, to secure more uniform distribution of the velocities across the section.

The governors are of the Woodward torsion shaft type, with motor-driven flyballs, and have a capacity of 42,000 foot pounds each at 200 pounds oil pressure. Two independent oil pressure systems are provided for the four units. Each pair of units has two pumps, either of which is capable of supplying both governors, one sump and one pressure tank. Pumps and pressure tanks for the adjustable blade units are approximately 50 per cent greater capacity than for the fixed blade

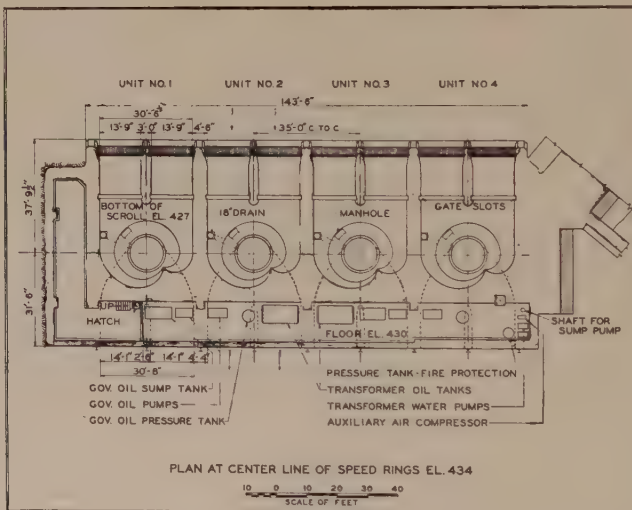


FIG. 5

units, to take care of the additional oil required for the runner blade servo motors.

All of the governor pumping equipment, together with auxiliary air compressor and circulating water pumps for the transformers, are located in the gallery below the generator floor at El. 430. The sub-gallery shown has no special function, except to save concrete in the substructure and to collect drainage from the levels above. No attempt is made to keep the lower gallery dry, although a vertical sump pump has been installed to avoid the possibility of flooding the pump gallery under high tail water.

TURBINE PERFORMANCE

The performances of single turbines of the fixed and adjustable blade types are compared in Fig. 6. The runners are of identical diameter and shape, the difference lying in the fact that the runner blades of the adjustable unit are simultaneously rotated on their axes with the wicket gates to maintain the best conditions of flow throughout the range of output. It will be noted that at full gate opening the adjustable blade turbine has approximately 30 per cent more capacity than the fixed blade turbine at the same head, and further, that the efficiency of the former is much greater than that of the latter, except at the point corresponding to maximum efficiency on the fixed blade wheel. From full load to 25 per cent load the efficiency of the adjustable

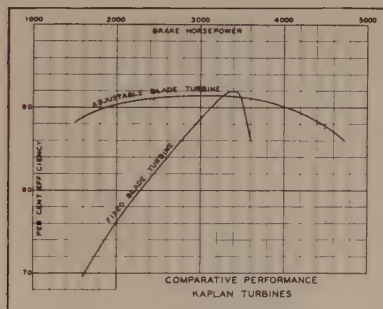


FIG. 6

blade unit is well over 80 per cent, whereas the fixed blade unit at a load as low as 25 per cent will drop to less than 50 per cent efficiency. It is interesting to note that the peak efficiency of the fixed blade unit exceeds the maximum efficiency of the adjustable blade unit by approximately one-half of 1 per cent. This is due to the fact that the discharge ring for the adjustable blade turbine is spherical only below the center line of runner blade trunnions, so that there is some leakage past the ends of the upper portions of the blades.

The curves of Fig. 7 indicate the reason for the selection of two adjustable units for this plant. The peaked curves show the turbine efficiency which might have been expected from four fixed blade units over the operating range from 600 to approximately 6,000 c. f. s. These curves are plotted directly from model tests of homologous runners, and are drawn for equal distribution of load upon as many units as are required to carry the station. The sharp valleys between these

curves indicate the large loss in efficiency at certain plant discharges, due to the inherent low part-gate efficiency of the fixed blade turbine.

The upper curve of Fig. 7 indicates the extent to which the operating efficiency is smoothed out over the range of plant discharge by the use of two adjustable and two fixed blade wheels instead of four fixed blade wheels. It will be noted that at the lower discharges adjustable blade units only are operated, with the load equally divided where both are running. At the higher discharges the fixed blade units are operated at a gate opening corresponding to maximum efficiency, with the remainder of the load equally divided on the two adjustable units. This combination results in practically 6 per cent greater average efficiency over the range of discharge than would be possible with most efficient

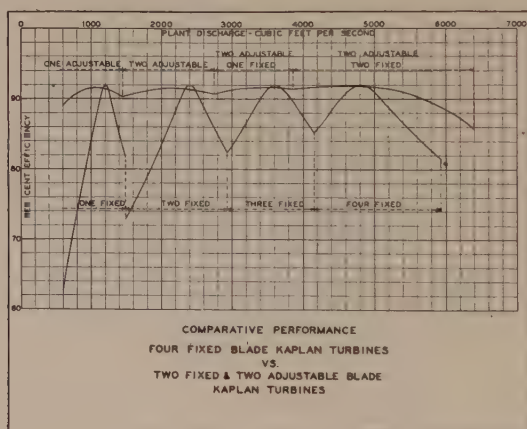


FIG. 7

operation of the four fixed blade units. It might be mentioned that the use of one adjustable unit out of four accounts for the greater portion of this gain in efficiency, but two adjustable units were installed at McIndoes Falls as a precaution against large loss of efficiency should the adjustable unit be out of service. The increased capacity of the adjustable units at full gate opening is only of value at McIndoes Falls under very greatly reduced head.

ADJUSTABLE BLADE CONTROL MECHANISM

Fig. 8 illustrates diagrammatically the general method of operation of the adjustable blade Kaplan turbine. The conventional wicket gates and operating mechanism are shown in relation to the movable runner

blades and their operating mechanism with its pressure oil control system.

The position of the runner blades is controlled by a piston moving vertically in an enlargement of the main turbine shaft immediately below the generator, which forms the operating servo motor. This piston is connected by a long rod passing through the length of the turbine shaft to a yoke and set of levers within the runner hub. Oil under pressure from the governor system is supplied to the runner servo motor from an auxiliary control valve located adjacent to the governor and mechanically connected to the wicket gate operating

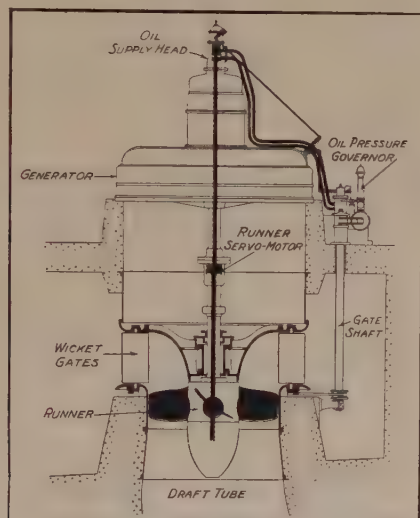


FIG. 8. — DIAGRAM OF SMITH-KAPLAN
TURBINE (BLADE CONTROL)

mechanism. This connection is in the form of a cam, the shape of which is experimentally determined to obtain a definite position of the runner blades for each position of the wicket gates. The control valve is connected to an oil supply head mounted on the frame of the exciter at the extreme top of the generator by means of two pipes, one serving as a supply, and the other as a return. The control valve supplies pressure oil to one or the other of these pipes, depending upon the direction in which the runner blades must be moved. From the oil head the oil is carried down to the servo motor through two concentric pipes passing through the entire length of generator shaft. The outer pipe

terminates in the space above the piston in the servo motor, whereas the inner pipe is firmly connected to the piston through which openings are provided communicating with the space below the piston. It is therefore evident that both oil pipes rotate with the shaft, but that in addition to its rotary motion the inner pipe moves vertically with the

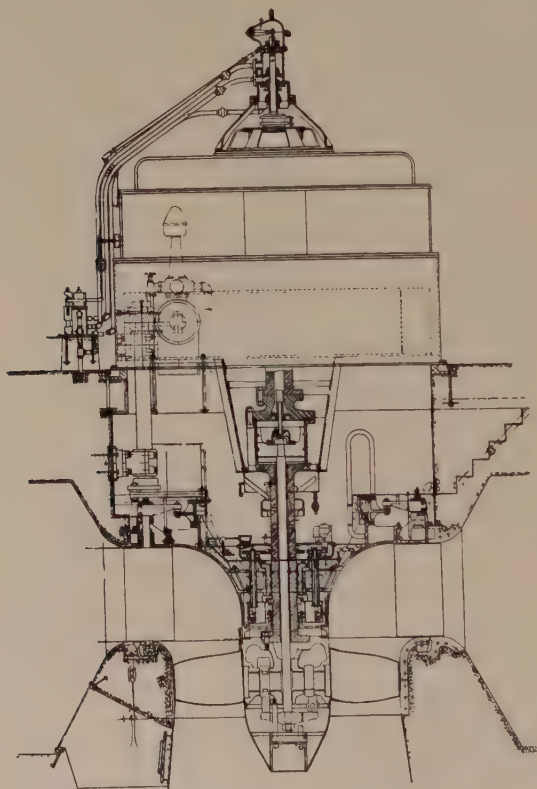


FIG. 9. — ADJUSTABLE BLADE UNIT

operating piston. This vertical movement is communicated back to the control valve through a series of levers and rods shown above the generator, thus acting to restore the control valve to its neutral position and to prevent overtravel and hunting of the runner blades.

Fig. 9 is a section through the adjustable blade unit, and illustrates the foregoing details as applied to the McIndoes Falls turbine. The oil head is mounted on a casting above the exciter bracket, the cast-

ing having openings to permit access to the brushes, slip rings, etc. The runner blade control valve is located on the generator floor adjacent to the governor. To avoid possibility of danger to the operators, all of the oil pipes leading from the oil head to the control valve, as well as the compensating connections, are provided with insulating couplings.

The oil supply head is a double compartment casting, with openings connected to the oil supply pipes. The outer oil pipe passing through the generator shaft terminates in the lower chamber of the oil head. The inner concentric pipe passes completely through the head, but holes are provided in the side walls communicating with the upper compartment. Special packing boxes, using a hollow lead ring type of packing filled with graphite, prevent leakage of oil where the pipes pass through the head. This packing is self-lubricating. Suitable drains are provided to carry any oil leakage to a container on the generator floor. Since the inner pipe rotates with the turbine, as well as having axial motion, it is apparent that there can be no pin connection between the pipe and the compensating mechanism. This mechanism is therefore weighted to keep the ball on the end of the compensating mechanism always in contact with a spherical seat in a plug in the upper end of the oil pipe.

The runner blade servo motor, which is immediately below the generator pedestal, is surrounded by a protecting housing or guard supported from the under side of the thrust bearing bracket. This guard in turn carries an oil pan into which such oil as may leak along the operating rod from the lower side of the servo motor is collected through a small spout in the side of the turbine shaft. Immediately below this oil pan is a small housing communicating by means of a hole through the shaft with the space between the operating rod and the bore through the turbine shaft. Its purpose is to permit filling of the runner hub with oil. An air vent is provided in the shaft opposite the filling opening. The filling opening is kept as high on the shaft as possible, so that a static head of oil is maintained at all times within the runner hub, which, added to the pressure within the hub caused by centrifugal force, produces a total head in excess of the water pressure on the outside of the hub, so that any leakage is in an outward direction, thus preventing the passage of sand or silt from the water into the operating parts in the hub.

The interior details of the runner blade servo motor are relatively simple, the lower ends of the two oil pipes being clamped into flanges which are bolted to the lower end of the generator shaft and to the

top of the piston, respectively. The bushing at the bottom of the cylinder, where the main operating rod passes through, serves to prevent excessive leakage of oil down through the shaft.

The size of the runner blade servo motor is determined with an ample margin of safety to give positive control of the blades at all times with the usual governor oil pressure. The force required to move the blades is the sum of the hydraulic unbalance and of the frictional resistance in the trunnions, due to the hydrostatic pressure and to the centrifugal force tending to throw the blades outward. In the case of a large runner under relatively high head, the latter is an appreciable item. At McIndoes Falls the governors are designed to move the wicket gates with a normal pressure of 150 pounds. Less than this is required for movement of the runner blades.

BLADE OPERATION

The sequence of operation is as follows:

As the load changes, the governor immediately begins to move the wicket gates to the correct position. The auxiliary control valve is immediately moved off its neutral position, which admits oil under pressure to one side or the other of the runner servo motor, simultaneously exhausting the oil from the opposite side of the piston. The runner blades then begin to move, but at a rate considerably slower than the rate of movement of the wicket gates. In the case of the McIndoes turbines the wicket gates are designed to move over their full range in approximately $2\frac{1}{2}$ seconds, whereas the runner blades require about 8 seconds for full travel. By the time the runner blades have reached the correct position for the new position of the wicket gates the compensating mechanism attached to the inner oil pipe has restored the control valve to its neutral position, and no further movement of the blades takes place until the wicket gates are again moved.

ADJUSTABLE RUNNER

Fig. 10 shows the side elevation of the runner with the vanes in position corresponding to zero wicket gate opening. It will be noted that the vanes are practically in a plane at right angles to the shaft at their outer ends. As far as efficiency is concerned, there is little object in closing the runner vanes beyond the point where the discharge angle is approximately 6° . As a matter of fact, it is sometimes advisable not to permit closure beyond this point, because of the fact that further

closure results in a considerably greater gate opening required to start the wheel. The fixed blade unit will start with approximately .35 gate opening, whereas nearly half gate opening is required if the runner blade

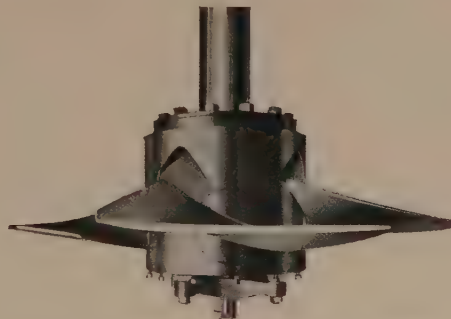


FIG. 10. — ADJUSTABLE RUNNER — VANES AT ZERO WICKET GATE OPENING

angle is carried much below 6° . On the other hand, on account of its very much higher part gate efficiency, the adjustable blade unit runs at synchronous speed with no load at a much lower gate opening than the



FIG. 11. — ADJUSTABLE RUNNER — VANES AT MAXIMUM WICKET GATE OPENING

fixed blade wheel. The runaway speed of the fixed blade unit is higher than of the adjustable, because the speed of a turbine with no load at full gate opening increases as the runner discharge angle is decreased.

A side view of the runner is shown in Fig. 11, with the blades in the position corresponding to maximum opening of the wicket gates. The discharge angle near the outer end is nearly 30° in this position. The corresponding angle of a fixed blade runner varies within certain limits, but is ordinarily made from 16° to 19° , depending to some extent upon the specific speed.

The operating mechanism inside of the hub is compact and rugged. The yoke on the lower end of the operating rod is connected to the levers on the blade trunnions by means of links. The levers are split to facilitate assembly. The hub is completely filled with heavy cylinder oil, which is prevented from leaking out along the trunnions by means of a special packing ring between the circular flange on the blade and the corresponding recess in the hub. The centrifugal force tending to throw the blades outward is taken on the sides of the split levers. The lower end of the hub is closed by an oil-tight cap.

All of the principal operating parts of the runner are made of cast or forged steel. Bronze bushings are used for the trunnion bearings. Especial care is used to finish the blades to template, so that they will all have exactly the same shape. The blade surfaces in contact with the water are carefully smoothed down by shaping and grinding to reduce to a minimum the friction of the water, and to avoid irregularities in the surface large enough to set up pitting. American practice differs in this respect from the methods followed in Europe, where the blade surfaces are actually machined for smoothness. There is, however, no data to justify such extreme refinement in construction.

GENERAL TURBINE DETAILS

The unit has but two guide bearings, the upper being located below the rotor of the generator in a common housing with the thrust bearing, and the lower being mounted on the turbine top plate. The turbine guide bearing is of the oil-lubricated babbitted type of the most recent design, in which the bearing shells are approximately one diameter in length. The oil circulating pumps are of the rotary gear type, one being driven by gears from the main turbine shaft, the other being motor-driven with float control, so that it automatically starts in the event of failure of the gear-driven pump. Leakage of water along the turbine shaft into the lubricating oil is prevented by means of the packing box immediately above the runner hub. Any water which does leak by is immediately picked up by an automatic float-

controlled motor-driven sump pump, which discharges it through the side of the turbine pit into the scroll case.

The details of construction of the major turbine parts are essentially the same as for the ordinary Francis turbine, except that the bottom plate or discharge ring is firmly embedded in the concrete structure. Earlier forms of propeller wheels were provided with removable bottom plates, but these designs proved unsatisfactory because of the tendency for such removable parts to work loose under the action of the water. The embedded bottom plate is much safer construction, and since it is made of cast steel it can be easily welded if pitting develops. The portion below the axis of the runner blade trunnions is made of spherical shape to maintain uniform clearance at the ends of the blades adjacent to the discharge edges. The upper portion is cylindrical to permit assembly and removal of the runner. The turbine top plate is of conventional design, with two bearings and a packing box for the upper ends of the gate stems. It is, however, made in two concentric sections, the inner of which is large enough so that the runner may be withdrawn without disturbing the outer portion of the top plate and the wicket gates. Provision has been made so that the runner hub may be fastened by means of straps to the lower portion of the inner top plate section, so that after removal of the generator the entire assembly, consisting of turbine shaft, top plate with bearing, and runner, may be removed as a unit. The purpose of this construction is to avoid the necessity of complete dismantling of the top plate, bearing, pumps, etc., in the event it is necessary to remove the runner for some minor repair within the hub.

The turbine pit and the opening through the generator pedestal are sufficiently large so that the top plate, which is the largest removable turbine piece, can pass through after the thrust-bearing bridge has been removed.

The oil pipes supplying the runner blade servo motor are removed by breaking the joint at the servo motor head, and raising the generator shaft sufficiently to permit access to the bolts holding the flanges by which the ends of the pipes are clamped in place.

FIXED BLADE UNIT

Fig. 12 is a sectional elevation of the fixed blade McIndoes unit, and shows by way of contrast the difference between this unit and the adjustable blade type. All of the details are identical with the adjustable blade unit, except for the omission of the oil head, servo motor and adjustable runner blades, and for the fact that the bottom plate is cylindrical instead of partially spherical.

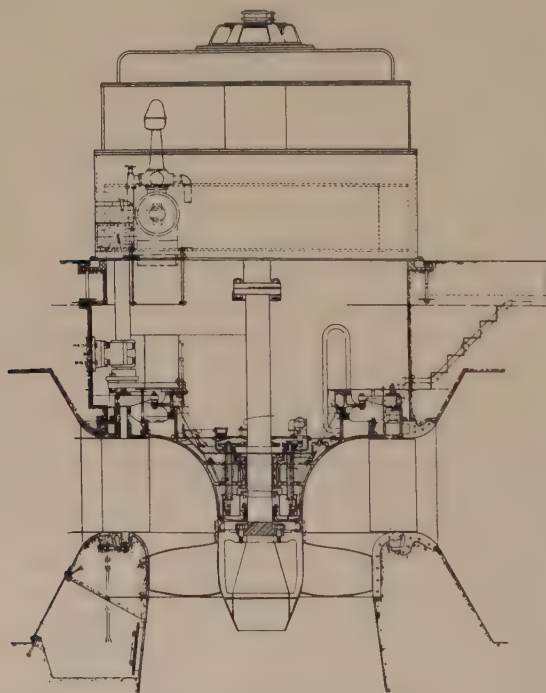


FIG. 12. — FIXED BLADE UNIT

DRAFT TUBE VENTING

An interesting feature of the design of the adjustable blade Kaplan turbine is the provision for admitting air to the draft tube at low gate openings. This air admission is, of course, absolutely essential to entirely break the draft tube water column when it is desired to motor the unit as a synchronous condenser. Failure to do so results in a severe drag and consequent large power loss due to churning of the

runner in the water. In addition, admission of air into the draft tube at low gate openings improves the operating efficiency somewhat, and greatly assists in maintaining smoothness of operation.

On account of the fact that the runner hub is entirely filled with operating mechanism, it is necessary to supply air to the draft tube by admitting it through the top plate into the space between the wicket gates and the runner. This is done by means of automatic valves, mechanically connected to the wicket gate mechanism, so that the valves are opened at a definite gate opening and remain open at all smaller gates. However, the transition space between wicket gates and runner is not always under vacuum, and, above .6 gate opening, positive pressure may exist in this space. This results in leakage of water through the air valve into the turbine pit if inwardly opening check valves are not used in series with the automatic air valves. This is true even if the openings through the top plate into the transition space are provided with deflectors which attempt to make use of the ejector action of the water to assist in drawing in air.

One disadvantageous feature of admitting air to the transition space is the fact that valves of large capacity are needed to admit air rapidly enough to prevent formation of a vacuum under the runner after breaking of the water column in the draft tube upon sudden rejection of load. This may result in a violent slap against the bottom of the runner as the water column returns. A further disadvantage is the fact that if the entire load is suddenly dropped from a unit the wicket gates are immediately tightly closed, and remain closed as long as the speed of the unit is above normal. This means that the runner continues to spin in air for a considerable period of time, since there is no drag from the water on the runner to assist in returning the speed to normal. In the case of the McIndoes turbines this objection was eliminated by a low gate limit device on the governor, which prevents full closure of the wicket gates, except manually, so that even upon total rejection of load the gates remain open approximately two-tenths, which maintains a column of water in the transition space, and aids greatly in the prompt return of the unit to normal speed.

SPEED REGULATION

The speed regulation characteristics of the fixed and adjustable blade units with load rejected are practically the same. This is due to the fact that as the load is dropped the amount of water passing through the wheel is controlled almost entirely by the wicket gates,

which move very quickly. On the other hand, if load is demanded, the wicket gates open quickly; but since the runner blades lag behind, actual control of the water passes from the wicket gates to the runner, and the entire load demanded cannot be carried by the unit until the runner blades have finally reached their correct position. This results in a considerably greater drop in speed with load demanded than is ordinarily the case with fixed blade turbines.

PRINCIPAL EQUIPMENT AT MCINDOES FALLS

Intake:

Rack rake: 1 Newport News 15 ft. rack rake.

Intake gates: 2 McClintic Marshall Co. structural steel gates, 13' 9" wide x 12' 0" high.

Intake gate hoist: 1 Philips & Davies, Inc., traveling gantry, with two hoists of 25 tons capacity each.

Spillway:

Skimmer gate: 1 McClintic Marshall Co. structural steel gate, 12' 0" wide x 13' 0" high.

Skimmer gate hoist: 1 Chapman Valve Co. twin-screw motor-operated hoist, 50 tons capacity.

Needle beam hoist: 1 Shepard electric tramrail hoist of 4,000 lbs. capacity.

Tainter gates: 3 McClintic Marshall Co. structural steel tainter gates, 24' 0" wide x 25' 0" high.

Tainter gate hoists: 3 Philips & Davies, Inc., double drum tainter gate hoists, 30 tons capacity each.

Flashboard cableway hoist: 1 Mead-Morrison 4-ton aerial cableway of 321 ft. span.

Power House — Mechanical Equipment:

Turbines: 2 S. Morgan Smith Co. fixed blade propeller type turbines, each rated at 1,250 c. f. s. capacity at 27 ft. net head, 150 r. p. m.

2 S. Morgan Smith Co. Kaplan adjustable blade propeller type turbines, each rated at 1,250 c. f. s. capacity at 27 ft. head, 150 r. p. m.

Governors: 4 Woodward Governor Co. 42,000 ft. lb. type H.R. gate shaft governors.

Power house crane: 1 Armington Engineering Co. 25 tons capacity, 27' 3½" span electric traveling crane, with one trolley and two independent hoists of 12½ tons capacity each.

Transformer cooling water pumps: 2 Allis Chalmers 2½" x 2½" type SSU capacity 100 g. p. m. at 100 ft. head.

Trash sluice pump: 1 Allis Chalmers 6" x 6" type SF double suction, single stage, centrifugal pump.

Sump pumps: 1 Worthington 1½" Monobloc type centrifugal pump, with float switch and Apco primer.

Station Service Air Compressor: 1 Ingersoll Rand 7" x 6" type 20, single acting vertical duplex air compressor, capacity 104 cu. ft. of free air per min. at 100 lbs. discharge pressure.

Governor oil tank air compressor: 1 Ingersoll Rand vertical two-stage type 30 air compressor, piston displacement 20 cu. ft. per min.; discharge pressure 200 lbs. per sq. in.

Power House — Electrical Equipment:

Generators: 4 Gen. Elec. Co. 3,300 kv-a, 2,400 v. 60 cycles 3 phase umbrella type generators, with direct-connected exciters and Gibbs thrust bearings.

Motor generator set — spare exciter: 1 Gen. Elec. Co. 50 kw, 125 v., 900 r. p. m. compound wound generator driven by a 75 h. p.-2,300 v. 3 phase 60 cycle induction motor.

Transformers: 4 Gen. Elec. Co. single phase, water-cooled outdoor transformers, each 4,400 kv-a, 2,300/33,000 v.

Discussion

HOWARD M. TURNER:* One or two things interested me especially in the reading of the paper, which I thought was a very fine one.

First, there was the figure chosen for flood capacity of the plant. The 1927 flood is given as 33,000 second feet on the Passumpsic, and on the Connecticut, at Waterford, as 31,000 second feet. There was a little additional drainage area on the Passumpsic which would have been tributary to that point, so that 65,000 second feet chosen for flood capacity was approximately what was obtained in the 1927 flood, assuming that the peaks of the floods on the main river and the Passumpsic came at the same time, which I think was probable. One thing which was discussed a great deal at our Flood Committee meetings was the question as to how much weight should be given large storage reservoirs in reducing flood capacity to be allowed for. The Fifteen Mile Falls Development has large storage above it, and of course the Upper Development will have still larger storage, so that if a flood greater than that of 1927 should occur — and I think it well might — one would have to count on the storage in the Fifteen Mile Falls plant to reduce the flood peak, which it undoubtedly would do. In this case there would be a large factor of safety in having large storage capacity available to smooth out the flood peak.

The second thing was the question as to whether, with the experience had with the Kaplan wheels and the experience at this plant, a future plant of this size and capacity would not perhaps be built with

* Consulting Engineer, 12 Pearl Street, Boston, Mass.

two Kaplan units instead of the four units installed. I understand that one advantage of high speed wheels, and particularly adjustable blade high speed wheels with high part-gate efficiency, is that the number of units can be reduced so that the station can be simplified and presumably the cost reduced. With a generator speed of 100 r. p. m. as against the 150 r. p. m., the speed of the McIndoes wheels, and the same specific speed, one could get the same capacity with only two units, and I think very close to the same efficiency and probably at less cost. I think Mr. Popp could tell us whether this would be practicable.

Another thing which Mr. Popp mentioned which interested me was this matter of the 8 seconds operation of the adjustable blades compared with $2\frac{1}{2}$ seconds governor operation which operates the wicket gates. Apparently it has some effect on the regulation with increasing load. What is the reason for that 8 seconds limit in the operation of these blades, against $2\frac{1}{2}$ seconds for the regulation of wicket gates, and how is the figure determined? It would be interesting if Mr. Popp would explain why and how this limit was set.

H. E. POPP: There is nothing very definite about the eight seconds time limitation for movement of the runner vanes. It is an average value that has been determined by experience as generally satisfactory. If the movement is too rapid, unnecessary wear of the runner control and operating mechanism will result. On the other hand, very slow movement might mean that under fluctuating load the runner vanes would lag so far behind the wicket gate movement that the correct relative positions would never be attained and the efficiency would suffer accordingly.

As far as the number of units is concerned, we did consider a two-unit installation, but found considerable advantage in four units for the McIndoes plant after careful study of all the elements entering into the total cost.

PROF. H. K. BARROWS: * The flood capacity of spillway, gates, etc., as given by Mr. Popp has reference to a water level of El. 454. This is not, however, the limit in safe flood capacity for this plant, as the water level can reach El. 460 without damage. For this latter elevation I estimate the capacity of spillway, gates, etc., at about 120,000 second feet, or a little in excess of the 1,000 year flood, according to Weston E. Fuller's method with $C=60$. There is also a very considerable additional factor of safety due to the storage at the Fif-

* Consulting Engineer, Boston, and Professor of Hydraulic Engineering, Massachusetts Institute of Technology.

teen Mile Falls plants and Connecticut Lakes, which will largely smooth out flood peaks.

The development at McIndoes up to 5,000 second feet corresponds to about 2.3 second feet per square mile, or approximately the flow available 30 per cent of the time — a common figure for a plant of this type. The pondage at McIndoes is sufficient to largely regulate the river flow to a 24-hour basis, as it comes from the Lower Fifteen Mile plant. The latter is a day load plant of very high capacity — about 7.5 second feet per square mile, which practically concentrates river flow in the daytime, and the McIndoes plant is of especial value in again smoothing out or regulating the flow to a 24-hour basis.

The Tainter gates at McIndoes are novel in this vicinity, although a common type of installation elsewhere. The provision for eliminating ice troubles by the use of compressed air has been worked out with unusual care, as is desirable for this locality.

Velocities are as follows:

POINT	Velocity (Feet per Second)	$\frac{V}{\sqrt{2gh}}$
Head gates	3.75	.09
Racks (gross)	1.85	—
Runner discharge	17.70	.42
Draft tube discharge	6.40	.15

These velocities at head gates and racks are about as usual; velocities at runner and draft tube discharge are a little higher than usual.

The Kaplan adjustable wheel units are noteworthy as to efficiency and its sustainment through a wide range of load. An effective way of showing this is by the "efficiency-load range ratio," which may be defined as the product of the efficiency, expressed as a ratio (limiting this to a minimum of, say, 0.80), and the range of load, expressed as a ratio to that at the full load point (point of maximum efficiency), taken as 1.00.

Thus the Kaplan adjustable wheel for which characteristics are shown in Fig. 5 has a range from 1,500 h. p. to 4,700 h. p. Full load is 3,000 h. p., so that the range of load, assuming that at the full load point as 1.0, is from 0.50 to 1.57. The average efficiency through this range is about 0.90 (expressed as a ratio). The efficiency-load range

ratio is therefore $1.07 \times 0.90 = 0.97$. This compares with other types of wheels as follows:

WHEEL	Specific Speed (Full Gate)	Efficiency- Load Range (Ratio)
Pelton (impulse)	4	.82
Low speed reaction	36	.68
High speed reaction	85	.40
Propeller — fixed blade	150	.20
Kaplan — adjustable	167	.97
Kaplan — fixed blade	146	.34

The remarkable characteristics of the Kaplan adjustable wheel as regards sustained efficiency are strikingly shown by a comparison of the efficiency-load range ratios in the above table.

The introduction of this type of wheel here in this country is undoubtedly one of the most important recent events in water power development.

It must be kept in mind, however, that the Kaplan adjustable wheel is adapted only for low heads — up to, perhaps, 60 feet, which limits very much its field of usefulness, as reaction wheel plants are now used for heads as high as about 1,000 feet.

The largest Kaplan units thus far in this country are the 42,500 h. p., 55-foot head, at the Safe Harbor development in Maryland, installed during 1931. These wheels are about 18 feet in diameter. At the Vargon plant in Sweden are Kaplan wheel units rated at about 15,000 h. p. under 14-foot head, which are about 26 feet in diameter.

This very excellent paper by Mr. Popp is a worthy continuation of the series of papers which have been presented to the society by the engineers of the New England Power Association, including those upon the Harriman, Bellows Falls and Fifteen Mile Falls plants. These power plants aggregate upwards of 350,000 h. p., all built within about seven years — a splendid block of power reaching the heart of the power market — constituting an important achievement in the development and use of our national resources here in New England.

WILLIAM FRANK UHL: * Mr. Popp has given us a very complete description of the McIndoes Falls Development. I am impressed with the great number of details which have been so thoroughly worked out

* Hydraulic Engineer, Chas. T. Main, Inc., 201 Devonshire Street, Boston, Mass.

in the design of this development, such as the handling of flood waters, the passing and handling of ice and trash, the use of air and electric heating elements to prevent the formation of ice where it might prove annoying, and the provisions for generator cooling. It is evident that the operating department was fully consulted, and that every attempt was made to provide it with a plant that could be operated with very few attendants and that would turn out the maximum output from the available water.

Of particular interest is the use of the adjustable blade propeller type runner in this station. To those of us who have for some time been interested in the design of hydraulic turbines, it is a great satisfaction to know that the second of the two great mechanical difficulties which prevented the attainment of good efficiencies at part loads has finally been overcome in such a satisfactory manner. In the earlier days of hydraulic turbine design, the admission of the water into the turbine runner was controlled by means of throttling devices, such as the cylinder and register gates, with low part gate efficiencies as a natural result.

The wicket or swivel gate method of water flow control, which was later developed, provided a smoother flow into the runner at part load and resulted in improved efficiencies at such loads. It took some time to perfect this type of gate mechanically, but as now generally used it is an excellent piece of mechanism and has solved the first of the two difficulties mentioned.

It was impossible to develop a method of controlling the runner orifices with the mixed flow type of turbine which gradually replaced all others, but it was only a short time after the propeller type of turbine was introduced before it was found possible to develop a design which permitted the manual adjustment of the blades and hence the orifices, and then it was only a short step from manual to automatic control.

Automatic adjustment of the blades and gates maintains the correct relationship between them to secure the highest efficiency for all load conditions.

The design of the mechanical details to accomplish this shows great ingenuity. It is interesting and important to know that the expectations as to performance at McIndoes have been fully realized, and that no troubles in operation have been encountered which are attributable to the adjustable blade design.

It is evident that a somewhat involved study is necessary to determine the economic adaptability of this type of turbine.

THEODORE B. PARKER: * I was particularly interested in the adjustable runner feature, inasmuch as I have been personally engaged in the design of a plant where we used the adjustable runner type. I think it is interesting to know that this feature has been used not only to gain more efficiency, but also to improve the output of a plant under varying head. That is really the other side of it.

There are one or two questions I want to ask Mr. Popp. I wonder just what clearance he had between the tips of the runner blades in the movable vane.

MR. POPP: I think it is three-sixteenths inches.

MR. PARKER: There is something I would like to suggest in this connection, perhaps of more general interest. Mr. Popp in his paper, and also other papers which we have heard read, described detailed arrangements which had been made to take care of ice, etc., We are frequently making such arrangements and trying to anticipate ice troubles. I think it might be of interest if some one would give a paper on actual operating experience with different types of gates and racks under winter conditions.

EDWIN A. DOW: † I should like to add a few words on the matter of flood capacity. We work on the assumption that the flood capacity of a plant should take into consideration not only the drainage area but the capacity and importance of the plant and the type of construction. At the McIndoes plant there are no earth dikes at either end of the dam. The construction is entirely of concrete, designed to afford a very substantial factor of safety, even with the water overtopping it; so even though we should have a flood exceeding the magnitude of the normal flood we would simply suffer inconvenience and damage due to flooding of the plant by high tail water, etc. Certainly nothing would go downstream, and there would be no disaster due to dam failure.

The flood capacity of a plant such as the Fifteen Mile Falls, with earth dikes, etc., must necessarily be far more generous than would be required for such a situation as that at McIndoes.

QUESTION: Will Mr. Popp tell us something about the allowable head variation? What percentage head variation can you have and still keep the efficiency up?

MR. POPP: This particular type of wheel is very well adapted to wide ranges of head. At the McIndoes Falls plant we can run down

* Project Engineer, Stone & Webster, Inc., 149 Federal Street, Boston, Mass.

† Designing Engineer, New England Power Engineering and Service Corporation, 89 Broad Street, Boston, Mass.

to as low as 15-foot head with good efficiency, as compared with a maximum head of about 30 feet — a rather wide range.

JOHN B. DRISKO:* Although they have been but recently introduced into this country, Kaplan turbines have been used for eight or ten years in Europe, where they have given good service and proved their value. A frequent location of Kaplan turbines in Europe is in a run-of-river plant, where only a single unit is installed, and must operate at widely varying conditions of head and discharge. Such plants may be made semi-automatic or full automatic.

At the Swedish plant, Lilla Edet, one Kaplan unit of 11,200 h. p. is used in conjunction with two Lawaczeck propeller units of 10,000 h. p. each. At another recent plant, Lanforsen, there are four Kaplan units of 13,000 h. p. each under a head of 30 feet.

Kaplan turbines have been installed under heads as high as 56 feet, and may be used at heads up to 65 feet, with certain limitations as to specific speed.

The Kaplan wheels manufactured by Verkstaden, of Kristineham, Sweden, differ from those of German manufacture in the location of the servo motor which actuates the runner blades. The German wheels are similar to the unit described by Mr. Popp, having the servo motor in the shaft between generator and turbine. The wheels by Verkstaden have the servo motor mounted in the runner hub, which simplifies both design and operation. The hub of a Kaplan wheel is of necessity large, — about 40 per cent of the wheel diameter for those made by Verkstaden, — and offers ample space for the servo motor.

With the more intense development of water power, and with the increasing demand for maximum utilization of available flow, the Kaplan turbine is of distinct advantage.

W. D. HENDERSON:† I am doing some work on a hydroelectric development in which a Kaplan turbine has been installed. As the adjustable blade turbine is of particular interest at this meeting, a few details of this other installation may be of interest.

The plant of which I speak is a 10,000 horsepower redevelopment on the Black River in Watertown, New York. The river falls about 100 feet through the city in six steps in a distance of a little over three miles. Each step has been developed, and, as might be expected with their close proximity, there is negligible pondage at all except the uppermost step. The plant is located on the next to the lowest step, so that it operates as a run-of-river development. However, the use of water above results in a very marked and rapid change of river flow at the

* Of Winchester, Mass.

† Engineer, Jackson & Moreland, Park Square Building, Boston, Mass.

site, amounting in dry periods to as much as 50 per cent increases and proportional decreases occurring within the period of an hour. Furthermore, for about 40 per cent of the time the flow is approximately three times the lowest flow with the present head-water storage, and, as is commonly the case, the head at the site is considerably reduced at the higher flows.

These conditions of river flow are ideal for the Kaplan turbine, but the studies made to determine the number and size of units indicated that with two units of about the same capacity only one needed to be of the Kaplan type. The slightly greater gain from two Kaplan turbines did not justify the greater cost in this particular case. Compared with three units having Francis runners of high efficiency, all of the same capacity, totaling 10,000 horsepower, selected in studies of the re-development made in 1920, the two-unit plant with propeller runners, one of the Kaplan type, will generate a greater kilowatt-hour output. This is because of the better efficiency of the adjustable blade turbine at part-load gate openings and because of its excess capacity which develops more nearly the full generator capacity at times when head is reduced by flood than is possible with any fixed vane runner.

There are a number of comparisons between the Watertown plant and the McIndoes plant Mr. Popp has so clearly described, which may be worth mentioning.

Both stations have integral intake and power house substructure, so that the waterways are much alike. In both, all units have the same size generators, and the total generator capacity is divided equally between fixed blade and adjustable blade turbine units. In both, the speed and the diameter of the fixed blade and adjustable blade turbines are alike. Also, in both, the top plate of each turbine is divided concentrically so that by use of a special distance piece placed between a collar on the shaft and the top plate, the turbine shaft runner and inner top plate section may be withdrawn as a unit, without disturbing the wicket gates, through the generator stator, after the generator rotor and bridge supporting the thrust bearing have been removed.

The gross head of the Watertown plant is 30 feet. The diameters of the turbine runners are 118 inches, and the speed is 150 revolutions per minute (which is also the speed of the McIndoes units). The generators are each 5,000 kilovolt amperes in capacity, and, like those at McIndoes, are of welded steel construction of the overhung type, with the thrust bearing and single steady bearing assembly supported by a steel bridge just below the generator rotor.

The turbines, which were built by I. P. Morris, have some interesting features. One innovation in their construction is the use of welded plate steel and structural shapes for the inner of the two concentric sections of the top plate. This section carries the steady bearing housing, and looks very much like an inverted Puritan's hat. The bearings are rubber lined, water lubricated. The adjustable blade runner has five blades, while the fixed blade runner has six. Both turbines have identical parts except for the runners and shafts; that is, the throat pieces, speed rings, wicket gates, gate operating mechanism, bearings and top plates are identical. As at McIndoes, the throat pieces are of cast steel, but they differ in that the throat for the fixed blade unit is semi-spherical like that for the adjustable blade unit, and not cylindrical. This was made to permit converting the fixed blade turbine to an adjustable blade turbine should it be desired later to do so. As the throat piece is a single steel casting embedded in the concrete structure, it would be expensive to replace it. In so far as the turbine is concerned, it will be necessary to replace only the runner and shaft, and to add the runner blade control equipment to the governor to make the conversion to the Kaplan type. There is some thought that reliability might later demand the change, since the one adjustable blade unit will be run the larger part of the time, as it, of course, should carry all loads less than, and all increments of loads greater than, the capacity of the fixed blade unit.

PROF. CHARLES B. BREED: * I think one aspect of the Kaplan type which we ought to keep in mind in this country is the fact that it is limited in use to practically low-head plants. I think the highest head in this country is about 60 feet. I believe abroad they have used them, perhaps, up to 70; but when we think that reaction wheels are used up to 1,000 feet, the range of heads in which this wheel will fit is a very small proportion of the ranges that we have to consider, so, unfortunately, it is limited in that respect.

MR. HENDERSON: Mr. Popp pointed out the difference in efficiency between the fixed and the adjustable blade types was because of the size of the throat piece. Where we had two spherical throat pieces, one on the adjustable and one on the fixed blade unit, we got about the same efficiency.

* Professor of Railway and Highway Transportation, Massachusetts Institute of Technology, Cambridge, Mass.

OF GENERAL INTEREST

BOSTON SOCIETY OF CIVIL ENGINEERS SCHOL- ARSHIP IN MEMORY OF DESMOND FITZ- GERALD AWARDED TO JOHN L. FREIHEIT, STUDENT AT NORTHEASTERN UNIVERSITY

John L. Freiheit, a senior in the School of Engineering at Northeastern University, whose home is in Shelton, Connecticut, was awarded the Desmond FitzGerald Scholarship of the Boston Society of Civil Engineers on April 20, 1932. The presentation of the scholarship of \$100 was made by Ralph W. Horne, President of the Boston Society of Civil Engineers, at a meeting in Jordan Hall attended by 1,200 students of the University.

Mr. Freiheit has been an honor student at Northeastern University for the past four years, and was unanimously recommended by the committee of the University consisting of Prof. Henry B. Alvord, head of the Department of Civil Engineering, Prof. Winthrop E. Nightingale, and Dean Harold W. Melvin, in accordance with the conditions of award established by the Boston Society of Civil Engineers.

PROCEEDINGS OF THE SOCIETY

JOINT OUTING, NEW ENG- LAND WATERWORKS AS- SOCIATION AND BOSTON SOCIETY OF CIVIL EN- GINEERS

The regular meeting of the Boston Society of Civil Engineers was omitted in June in order to join with the New England Waterworks Association in an outing which was held at the Oak Hill Country Club, Fitchburg, Massachusetts, on June 28, 1932.

Arrangements were made for inspection tours to the new Lovell Dam at Fitchburg and to the Notown Dam at Leominster, as well as to the Waterworks shops at both Fitchburg and Leominster.

A program of sports and stunts, games of bridge and golf, with prizes for the winners and a dinner for all, made the affair very enjoyable. About 200 members, ladies and guests attended.

The joint committee in charge consisted of a committee from the N. E. W. W. A., Herbert W. Jacobs chairman, and E. N. Hutchins and E. S. Averill of the B. S. C. E.

APPLICATIONS FOR MEMBERSHIP

[September 20, 1932]

THE By-Laws provide that the Board of Government shall consider applications for membership with reference to the eligibility of each candidate for admission and shall determine the proper grade of membership to which he is entitled.

The Board must depend largely upon the members of the Society for the information which will enable it to arrive at a just conclusion. Every member is therefore urged to communicate promptly any facts in relation to the personal character or professional reputation and experience of the candidates which will assist the Board in its consideration. Communications relating to applicants are considered by the Board as strictly confidential.

The fact that applicants give the names of certain members as reference does not necessarily mean that such members endorse the candidate.

The Board of Government will not consider applications until the expiration of fifteen (15) days from the date given.

For Admission

ALOFF, ABRAHAM MARTIN, Dorchester, Mass. (Age 24, b. Boston, Mass.) Graduate of Harvard College, with degree A.B., in 1929. From June to August, 1929, student at Harvard Engineering Camp, Squam Lake, New Hampshire; August and September, 1929, assistant on field engineering staff of Whidden-Beekman Company; 1929-30, student in Harvard Engineering School; August and September, 1930, assistant in field engineering staff, inspection of pile driving, Whidden-Beekman Company; October, 1930, to January, 1931, estimator with S. Aloff, Boston; February, 1931, to June, 1932, junior examiner, Division of Civil Service, Commonwealth of Massachusetts; July, 1932, to date, civil service examiner in professional subjects, Division of Civil Service, Commonwealth of Massachusetts. Refers to *E. S. Dorr, G. M. Fair, Albert Haertlein, L. J. Johnson, H. M. Turner.*

GILBOY, GLENNAN, Cambridge, Mass.

(Age 30, b. Duryea, Pa.) In architect's office from 1917 to 1921; student at Massachusetts Institute of Technology, 1921-25; assistant, M. I. T., 1925-26; research assistant, 1926-28; research associate, 1928-29; assistant professor, 1929-32; now associate professor of soil mechanics, in charge of research and instruction in soil mechanics and foundation engineering. Degrees (all M. I. T.): S.B., 1925; S.M., 1927; Sc.D., 1928. Refers to *J. B. Babcock, C. B. Breed, Arthur Casagrande, J. S. Crandall, C. M. Spofford.*

MYOTT, E. B.,* Reading, Mass. (Age 35, b. Barton, Vt.) From May, 1913, to March, 1916, rodman and transitman with Chandler & Palmer, civil engineers, Norwich, Conn., on land surveys, sewerage, street railway and miscellaneous construction work; March, 1916, to January, 1917, transitman and chief of party with Boston & Maine Railroad on bridge and track surveys and general drafting; February 18, 1917, to July 25, 1917, chief of party and assistant to construction superintendent, New York State Dredging Corporation, Strandway Improvement at Boston, engaged on line and grade work and assisting superintendent on hydraulic dredging and construction of outfall sewers; August 13, 1917, to April 20, 1918, chief of party and draftsman with Aspinwall & Lincoln on city surveys, lines and grades for building construction, and other miscellaneous field and office work; April 20, 1918, to August 1, 1918, draftsman with Fay, Spofford & Thorndike, Boston, Mass., on general field office work at Boston Army Supply Base; December, 1918, to date, draftsman, designer, resident engineer and senior engineer on investigations, reports, designs and construction of various municipal engineering projects with Fay, Spofford & Thorndike, consulting engineers, Boston. Refers to *C. A. Farwell, R. W. Horne, F. H. Kingsbury, O. E. Parks, A. D. Weston.*

DEATHS

WILLIAM WHEELER . July 1, 1932
COL. ORVILLE J. WHITNEY Aug. 21, 1932

* Revised statement.

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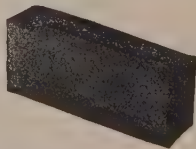
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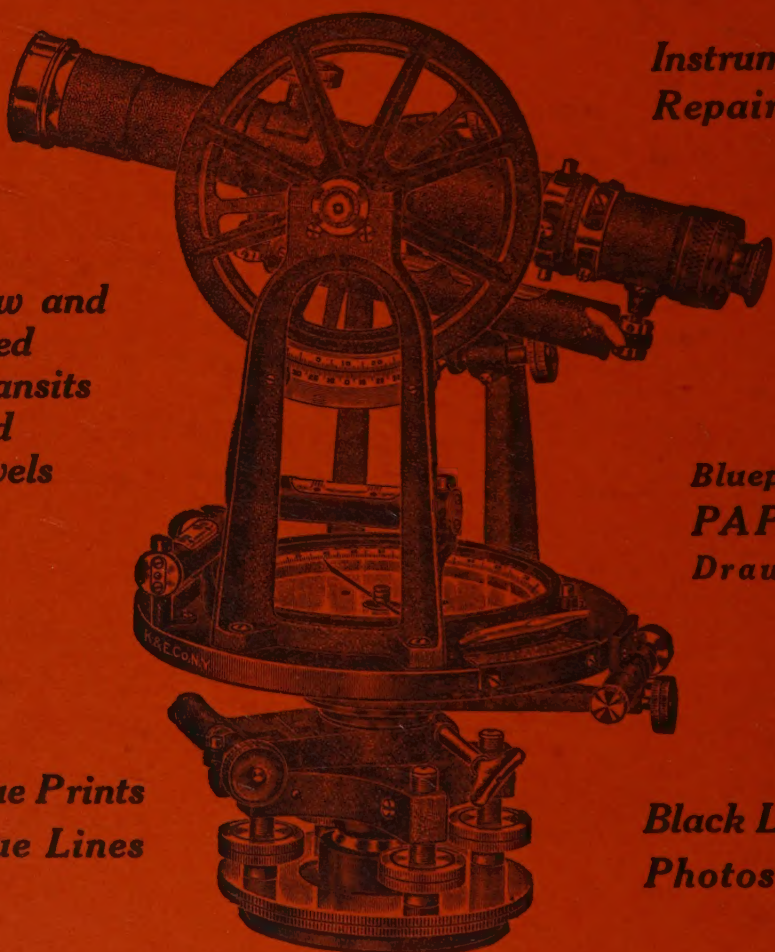
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